CHAPTER 24: WAVE OPTICS

24.1: YOUNG'S DOUBLE-SLIT EXPERIMENT

24.2: REFRACTIVE INDEX, LIGHT SPEED, AND WAVE COHERENCE

24.3 GRATINGS: AN APPLICATION OF INTERFERENCE

24.5 DIFFRACTION OF LIGHT

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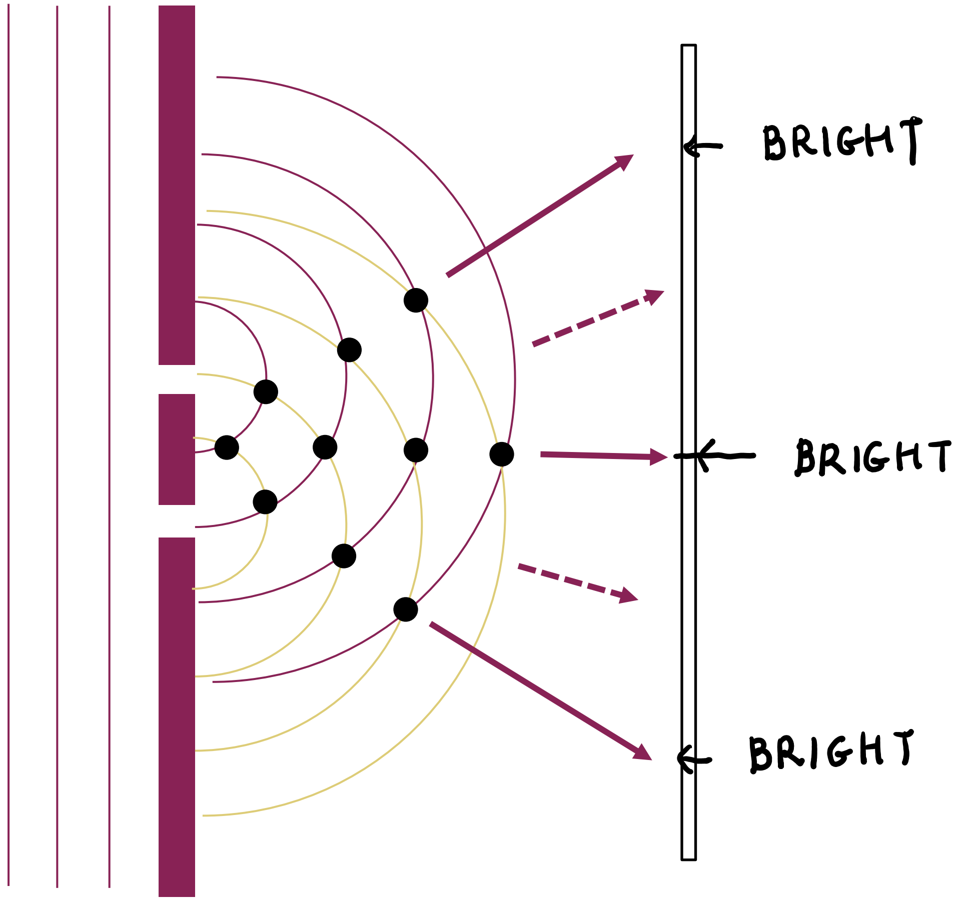
24.7 SKILLS FOR APPLYING THE WAVE MODEL OF LIGHT

24.4 THIN-FILMS INTERFERENCE*

24.1 Young's double slit experiment

https://www.falstad.com/ripple/



Dark dots indicate places where wavefronts meet

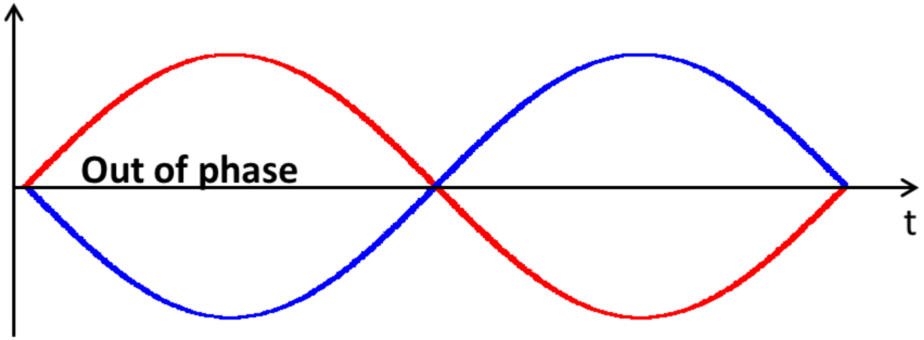
Coherence

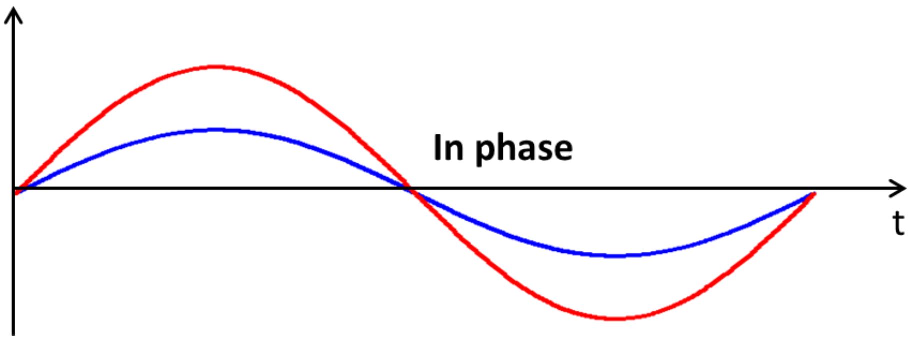
Two waves are **coherent** if:

1. They are monochromatic (single frequency/same wavelength)
2. There is a constant phase relation between them (in phase, out of phase or something in between).

Phase Terminology

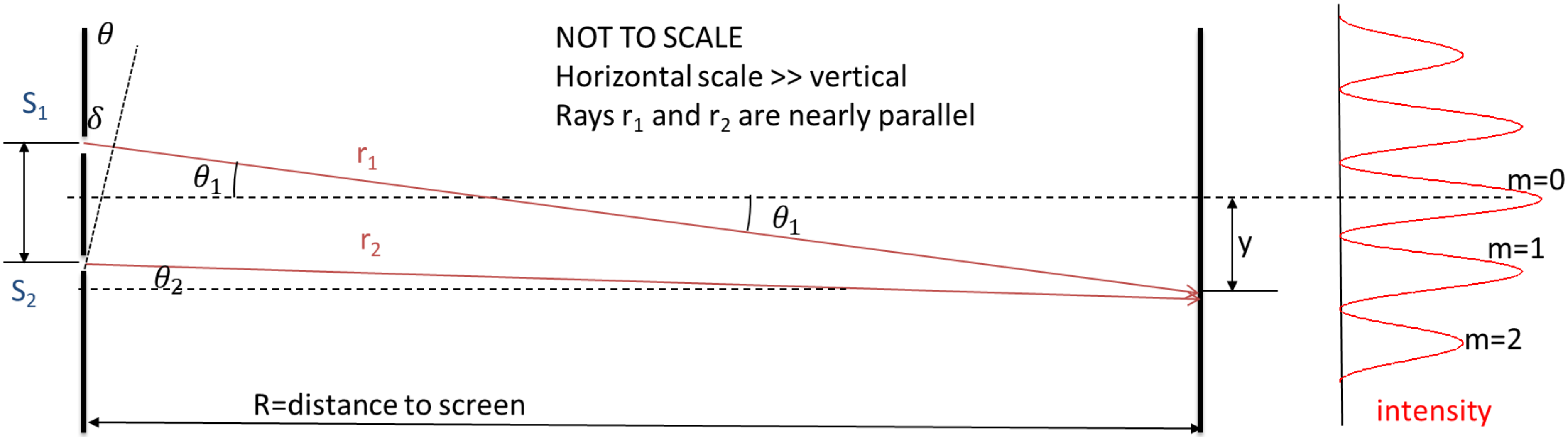
Waves are **in phase** at a particular position if they are at the same part of their cycle.





Note: frequency must be the same to meaningfully compare phases as a function of position

TWO-SLIT INTERFERENCE



Rays arrive **in phase** to the places where bright fringes are formed.

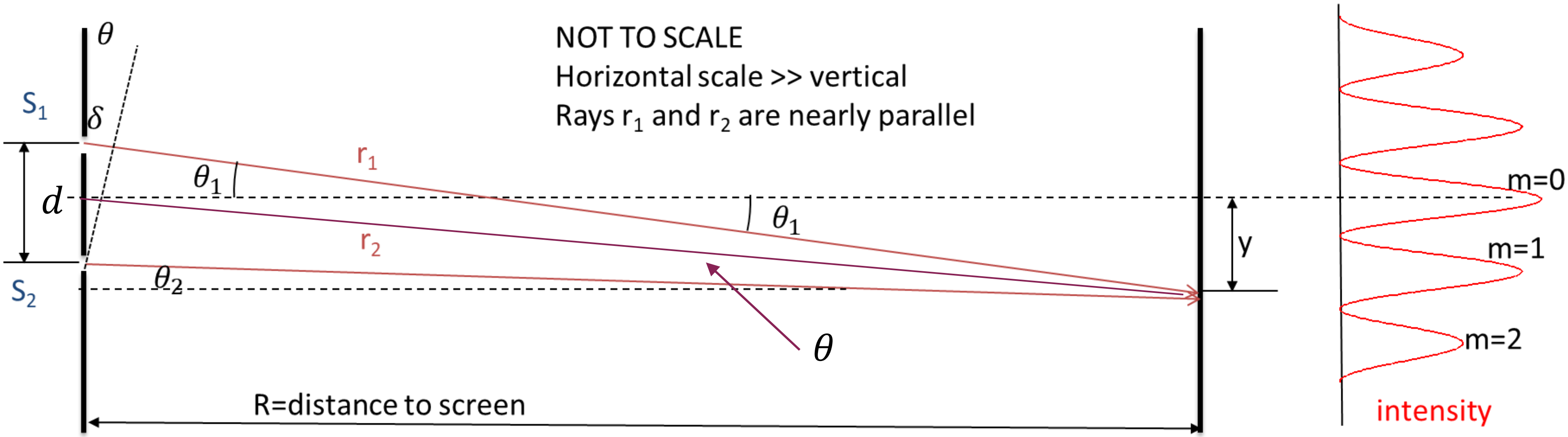
At 0^{th} order maximum (center) waves arrive after travelling through the same distance.

We say the **path difference** at that point is equal to zero, $r_2 - r_1 = 0$

At 1^{st} order maximum the wave from the closer source travels through the distance one wavelength shorter, $r_2 - r_1 = \lambda$

The same is true at two points (above and below 0^{th} order,
therefore a symmetric pattern is observed.

Two-Slit Interference



Mathematically – a bright spot is observed when path diffrence δ:

$$\delta = m\lambda$$

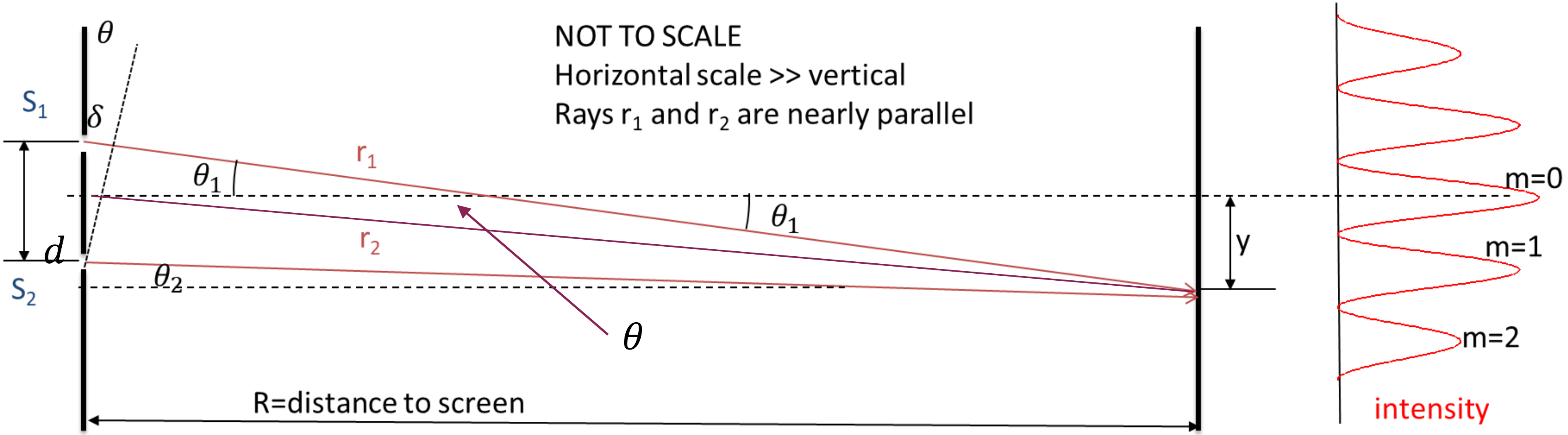
where $m = 0, \pm 1, \pm 2, \pm 3, \ldots$

$$\sin\theta = \frac{\delta}{d} = \frac{m\lambda}{d}$$

So, for any fringe m

$$\sin\theta_m = \frac{m\lambda}{d} \rightarrow d\sin\theta_m = m\lambda$$

Two-Slit Interference



The position of the bight post on the screen can be found if the distance between the screen and slits is known

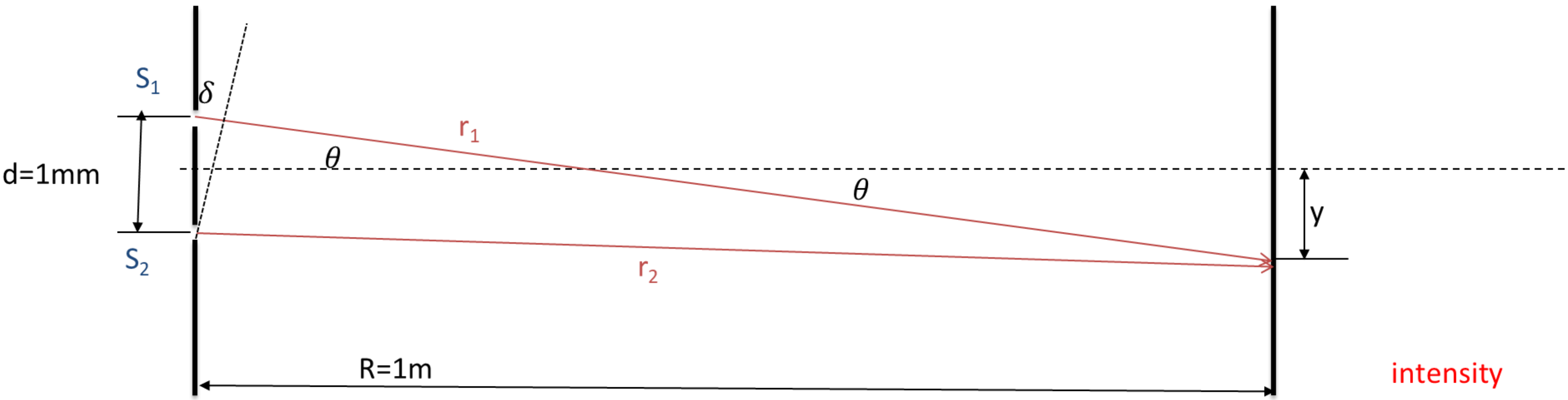
$$\tan\theta_m = \frac{y_m}{R}$$

Realistically, the distance to the screen (here R, your textbook uses L) is much larger than the distance y at which the bright spot is observed on the screen relative to the center maximum.

This means that θ_m is a small angle and our favourite approximation:

$$\tan\theta_\mathrm{m} \approx \sin\theta_m = \frac{m\lambda}{d} \rightarrow \frac{y_m}{R} = \frac{m\lambda}{d} \rightarrow y_m = \frac{m\lambda R}{d}$$

EXAMPLE 24A



Light with $\lambda = 500\ \mathrm{nm}$ is incident on 2 slits separated by 1 mm.

a) What is the position of the 1st order bright fringe? (angular)

Find the distance between the $m = 2$ and $m = 3$ bright fringes on a screen 1.0 m away.

a) $d \sin \theta_1 = m\lambda$ $\quad m = 1$

$$\sin \theta_1 = \frac{m\lambda}{d} = \frac{1 \cdot 500 \times 10^{-9}\ m}{1 \times 10^{-3}\ m} = 500 \times 10^{-6} = 5 \times 10^{-4}$$

b) $y_m = \dfrac{mR\lambda}{d}$

$$y_3 - y_2 = \frac{3R\lambda}{d} - \frac{2R\lambda}{d} = \frac{R\lambda}{d} = \frac{1.0m \times 500 \times 10^{-9}\ m}{1 \times 10^{-3}}$$

$$\Delta y = 5 \times 10^{-4}\ m$$

EXAMPLE 24A' (DIY - LC)

Light from a Nd:YAG laser (λ=532 nm) is incident on 2 slits separated by 0.125 mm. Find the distance between the $m = 2$ and the $m = -2$ bright fringes on a screen 4.0 m away.

$$y_m = \frac{m R \lambda}{d}$$

$$\Delta y = y_2 - y_{(-2)} = \frac{2R\lambda}{d} - \frac{(-2)R\lambda}{d} = \frac{4R\lambda}{d}$$

$$\Delta y = \frac{4 \cdot 4.0\,m \cdot 532 \times 10^{-9}\,m}{0.125 \times 10^{-3}\,\cancel{m}}$$

$$\Delta y \cong 6.8\ cm$$

EXAMPLE 24B

What is the longest wavelength λ that can produce an interference pattern using slits separated by d?

$$d \sin\theta = m\lambda$$

$$m = 1$$

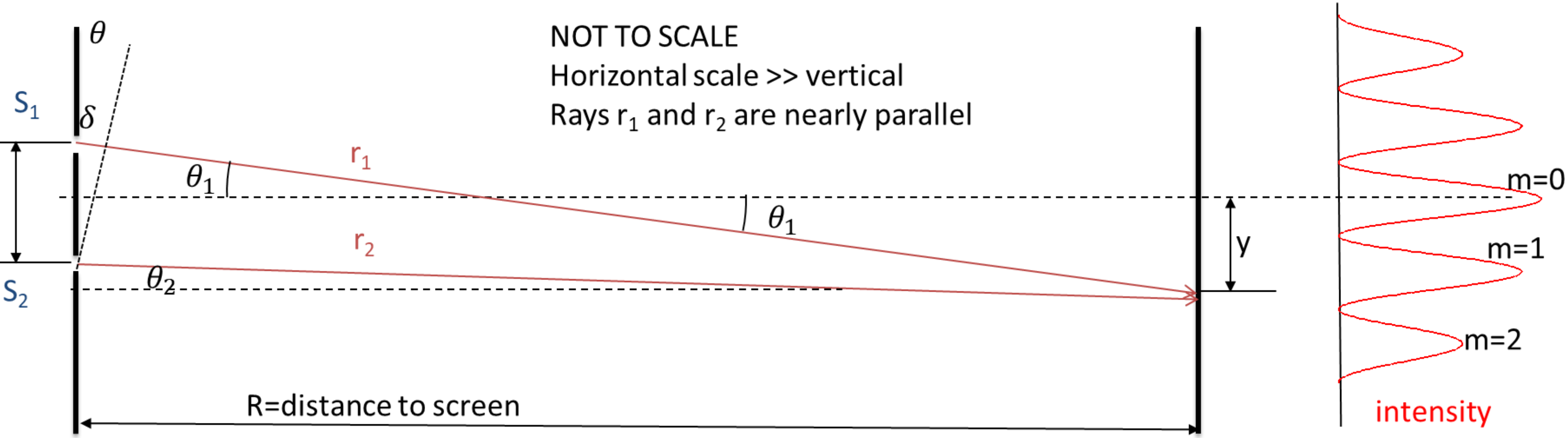
$$d \sin\theta = \lambda$$

$$\sin\theta = 1 \rightarrow d = \lambda$$

LEARNING CATALYTICS

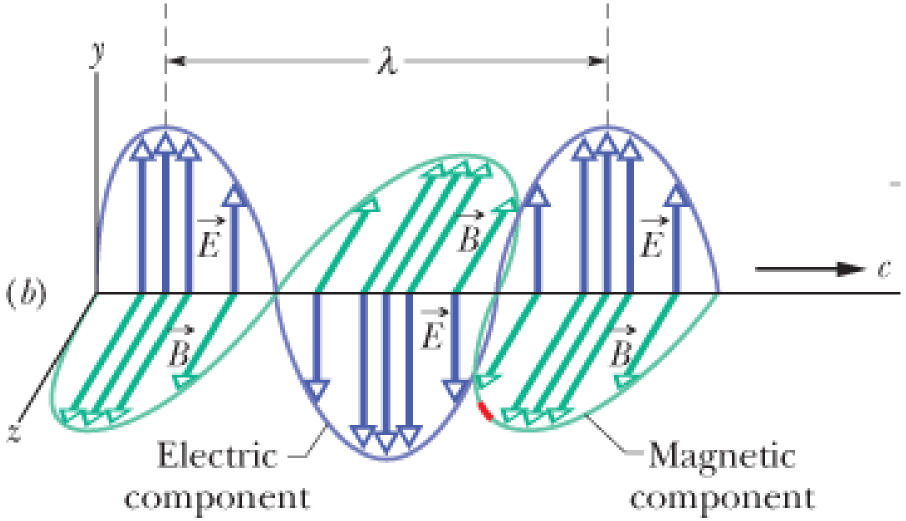
What is the path length difference between the center bright fringe (0^{th} order) and first minimum?

What equation could be used to find the location of the m^{th} minimum?



ELECTROMAGNETIC WAVES

Light is a travelling wave of electromagnetic fields



Halliday & Resnick Fig. 33-5

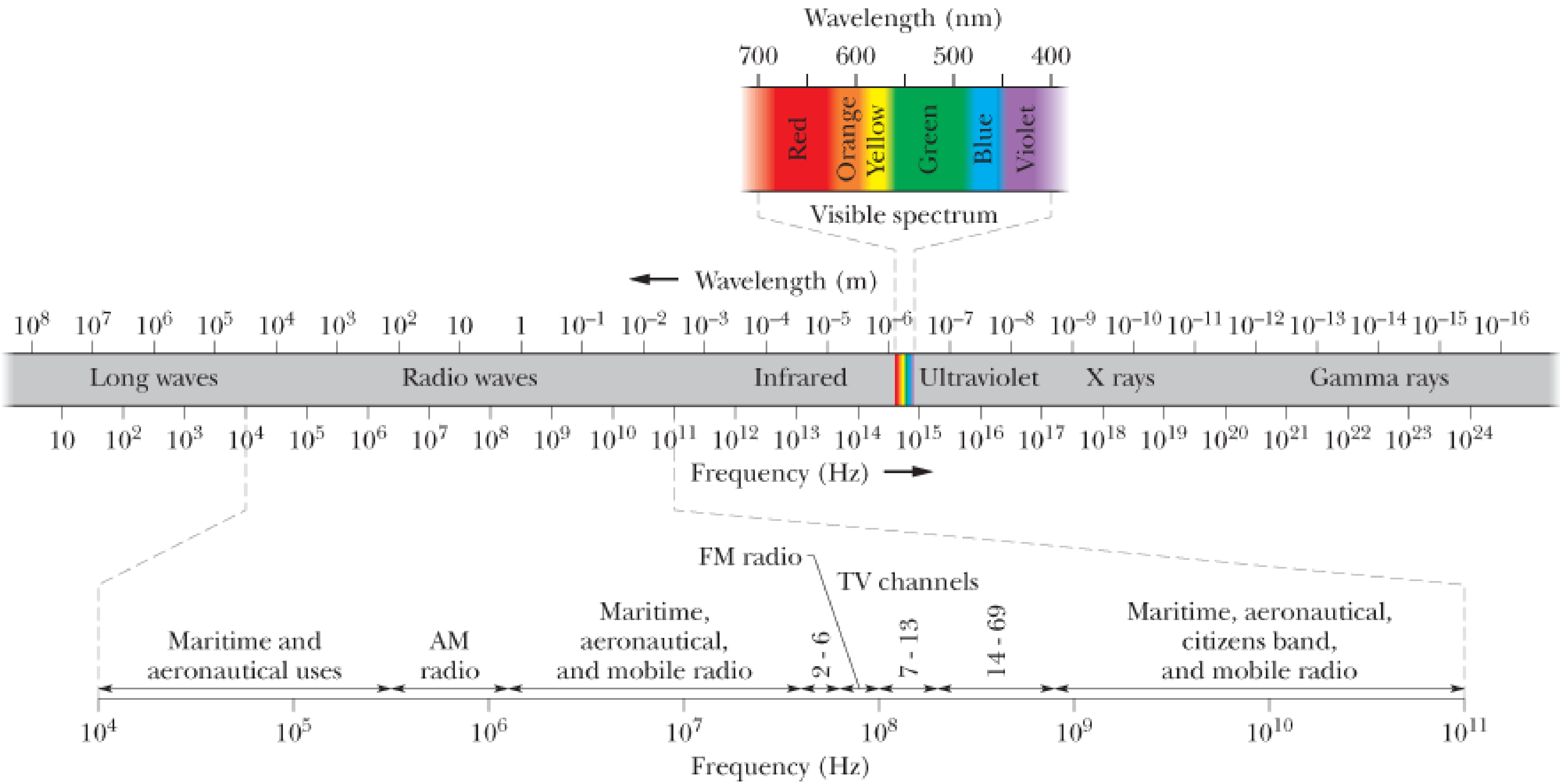
The speed of light in vacuum is defined (not measured) as

$$c \equiv 299\,792\,458 \text{ m/s}$$

$$c \approx 3.00 \times 10^{8} \text{ m/s}$$

Follows the same rules as the other waves we've dealt with, except for one exception: light has no preferred rest frame.→ $start\ of\ theory\ of\ relativity$

ELECTROMAGNETIC SPECTRUM



Halliday & Resnick Fig. 33-1

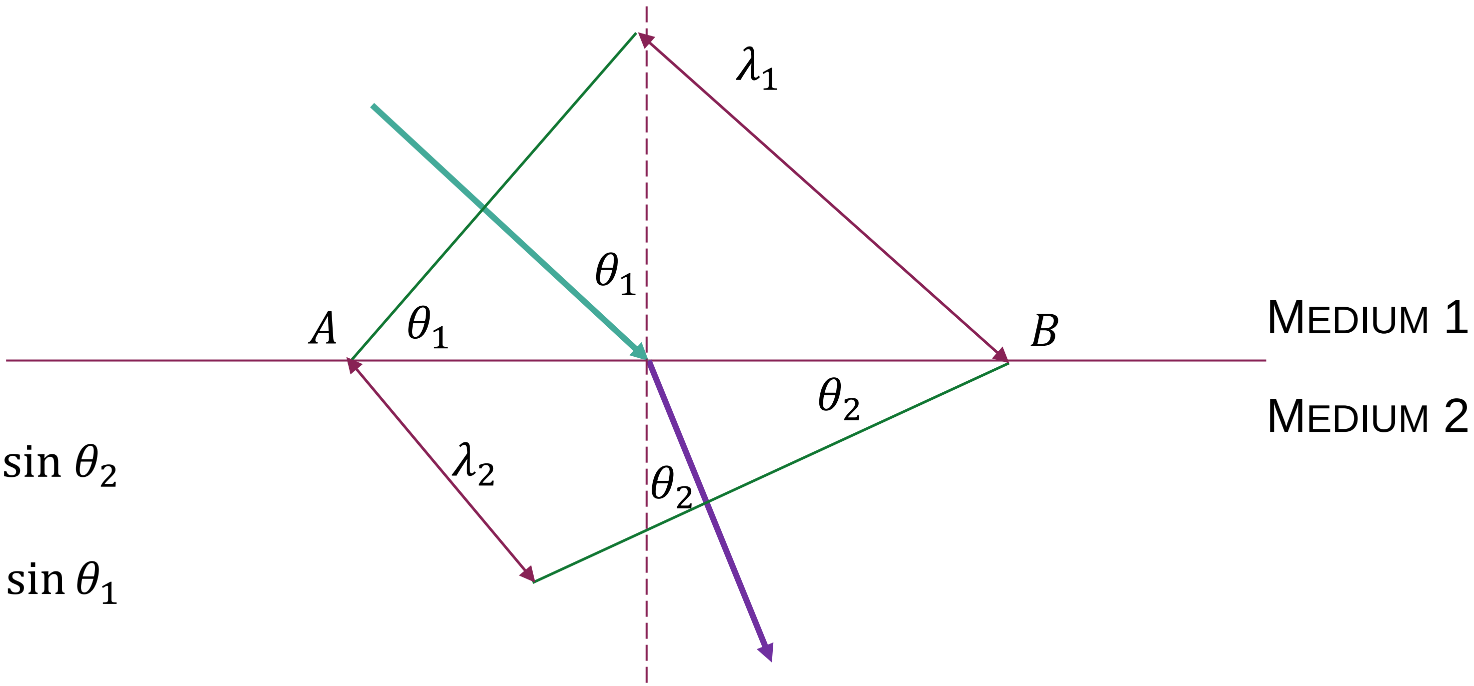
24.2 Refractive Index

Wave speed depends on the medium the wave is traveling through.
For light (and all electromagnetic waves), the speed in a medium can be calculated as

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

where c is the speed of light in vacuum ($3.0 \times 10^8\ \mathrm{m/s}$)

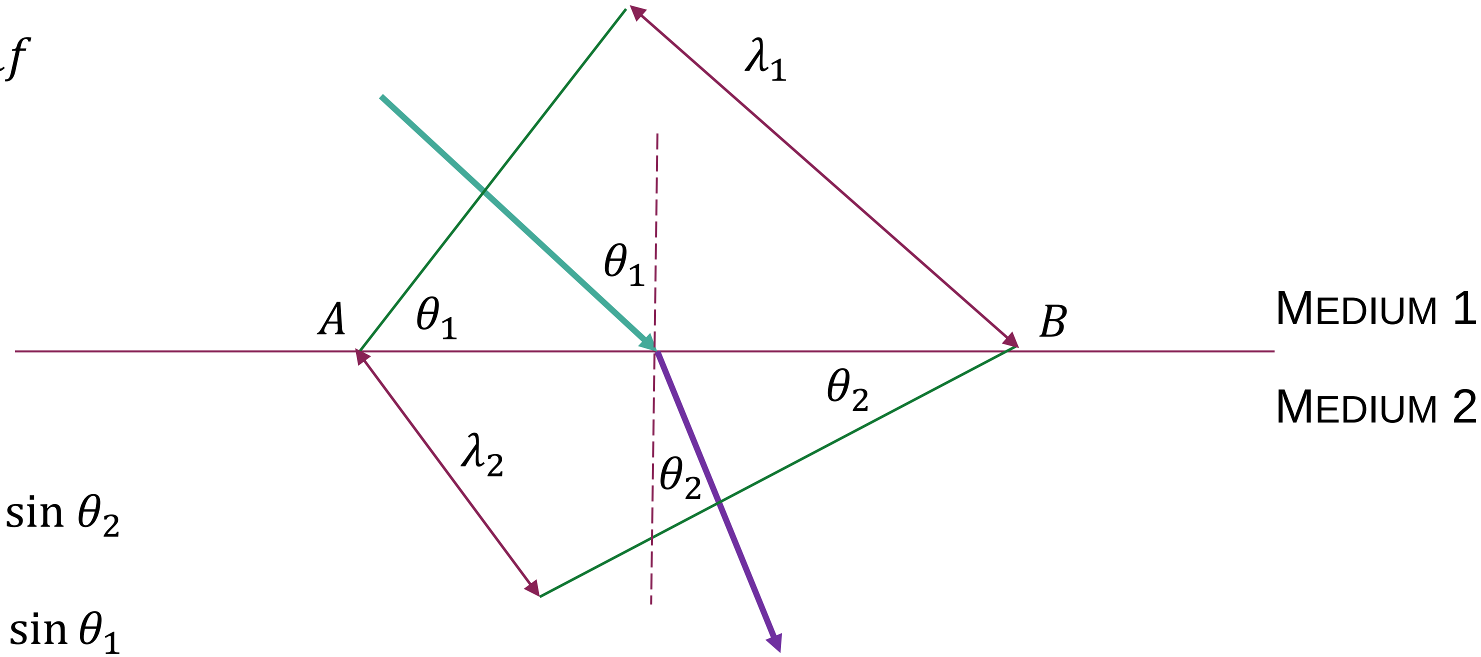
Just like for mechanical waves, **<u>when the wave slows down, its wavelength changes</u>**.



$$\frac{\lambda_2}{|\mathrm{AB}|} = \sin\theta_2$$

$$\frac{\lambda_1}{|AB|} = \sin\theta_1$$

$v = \lambda f$



$$\frac{\lambda_2}{|\mathrm{AB}|} = \sin\theta_2$$

$$\frac{\lambda_1}{|AB|} = \sin\theta_1$$

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{\lambda_2}{\lambda_1} = \frac{\frac{v_2}{f}}{\frac{v_1}{f}} = \frac{v_2}{v_1}$$

Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2 \rightarrow \frac{\sin\theta_2}{\sin\theta_1} = \frac{n_1}{n_2}$

$$\frac{v_2}{v_1} = \frac{n_1}{n_2}$$