INTERFERENCE, DI FFRACTION, POLARISATION

Interference, Diffraction & Polarization

Soap Film Interference Patterns

Light's Nature

- Wave nature (electromagnetic wave)

- Particle nature (bundles of energy called photons)

Past- Separate Theories of Either Wave or Particle Nature

- **Corpuscular theory of Newton** (1670)
- Light corpuscles have mass and travel at extremely high speeds in straight lines

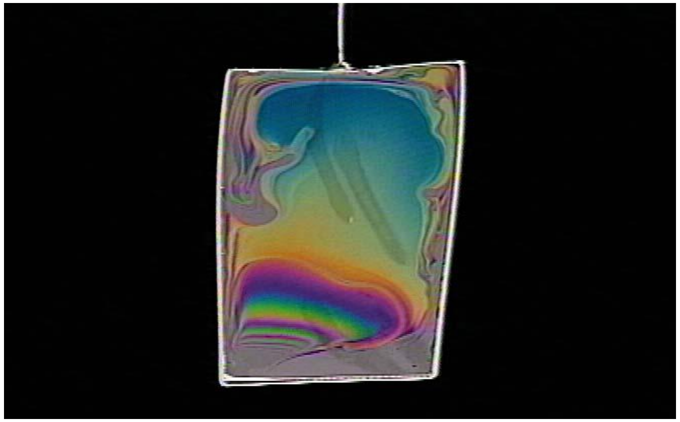
- Huygens (1680)
- Wavelets-each point on a wavefront acts as a source for the next wavefront

Proofs of Wave Nature

- Thomas Young's Double Slit Experiment (1807)

bright (constructive) and dark (destructive) fringes seen on screen

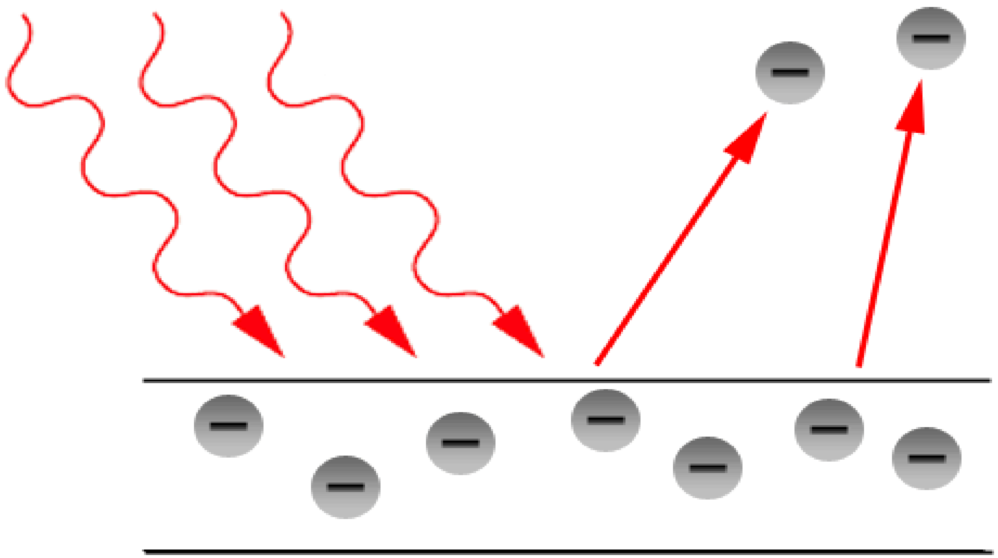
- Thin Film Interference Patterns



- Diffraction fringes seen within and around a small obstacle or through a narrow opening

Proof of Particle Nature: The Photoelectric Effect

- Albert Einstein 1905
- Light energy is quantized
- Photon is a quantum or packet of energy



The Photoelectric Effect

- **Heinrich Hertz** first observed the **photoelectric effect** in 1887

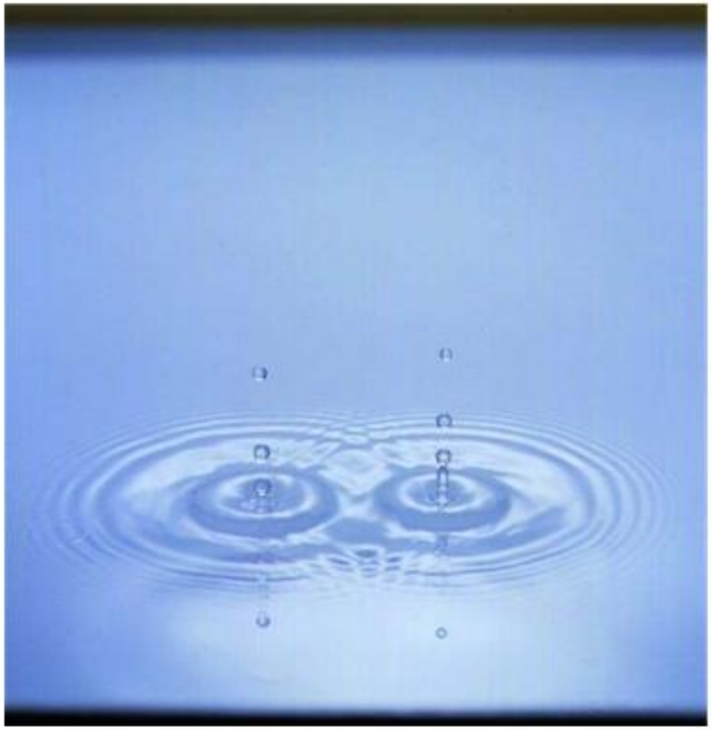
- Einstein explained it in 1905 and won the Nobel prize for this.

Light as waves

So far, light has been treated as if it travels in straight lines.

To describe many optical phenomena, we have to treat light as waves.

Just like waves in water, or sound waves, light waves can interact and form interference patterns.



remember

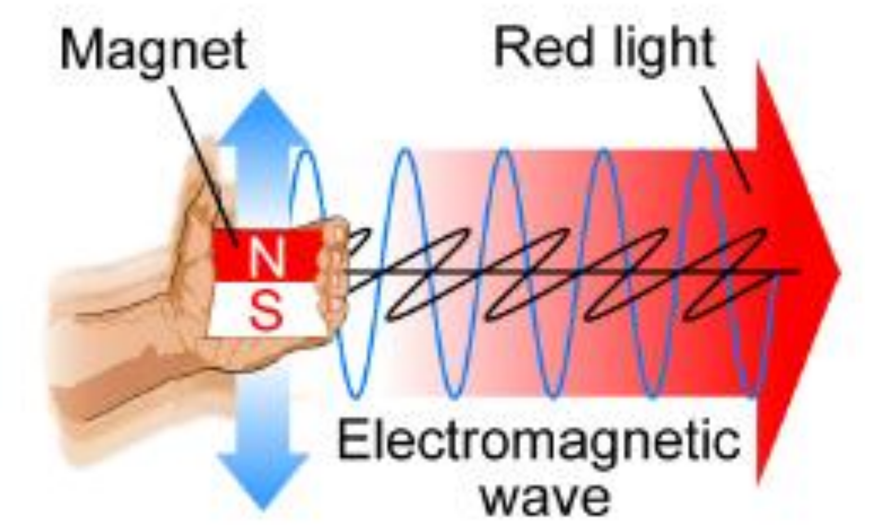
$c=f\lambda$

The Electromagnetic Spectrum

What is the electromagnetic spectrum?

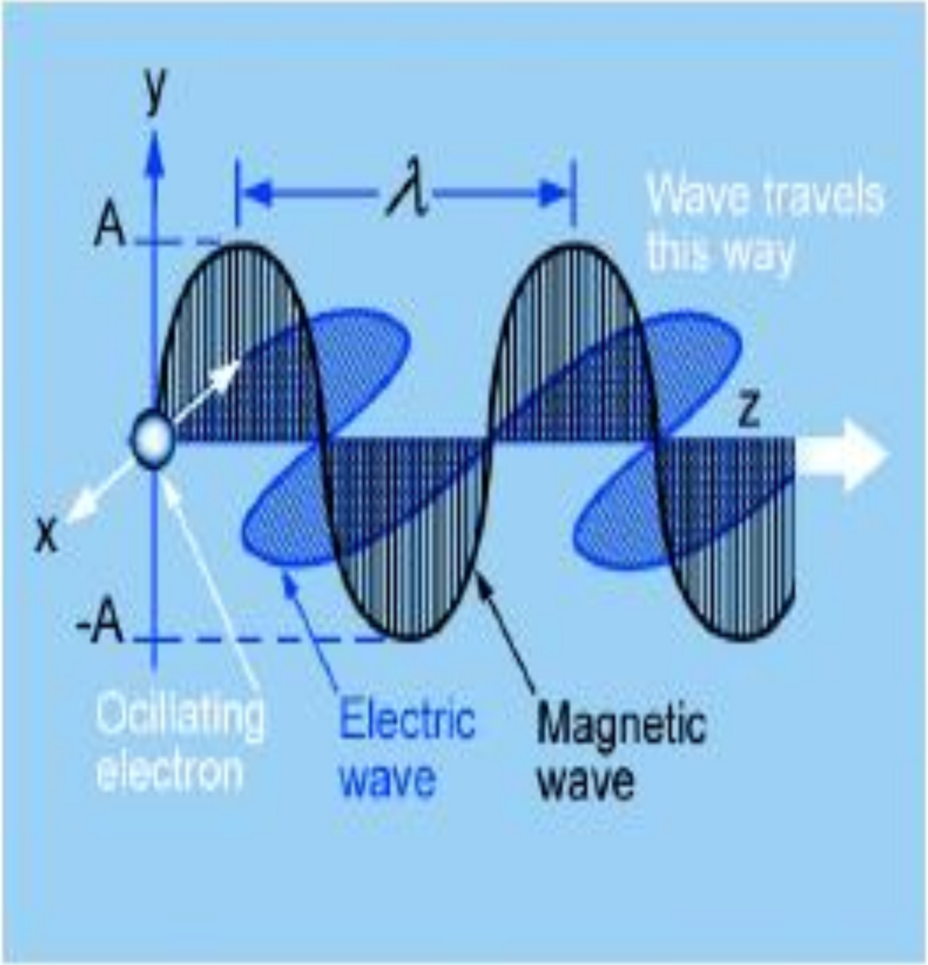
The Electromagnetic Spectrum

- **The energy field created by electricity and magnetism can <u>oscillate</u> and it supports waves that move.**
- **These waves are called electromagnetic waves.**



The Electromagnetic Spectrum

- **Electromagnetic waves have both an electric part and a magnetic part and the two parts exchange energy back and forth.**
- **A 3-D view of an electromagnetic wave shows the electric and magnetic portions.**



- **The wavelength and amplitude of the waves are labeled λ and A, respectively.**

The Electromagnetic Spectrum

- The higher the frequency of the light, the higher the energy of the wave.
- Since color is related to energy, there is also a direct relation between color, frequency, and wavelength.

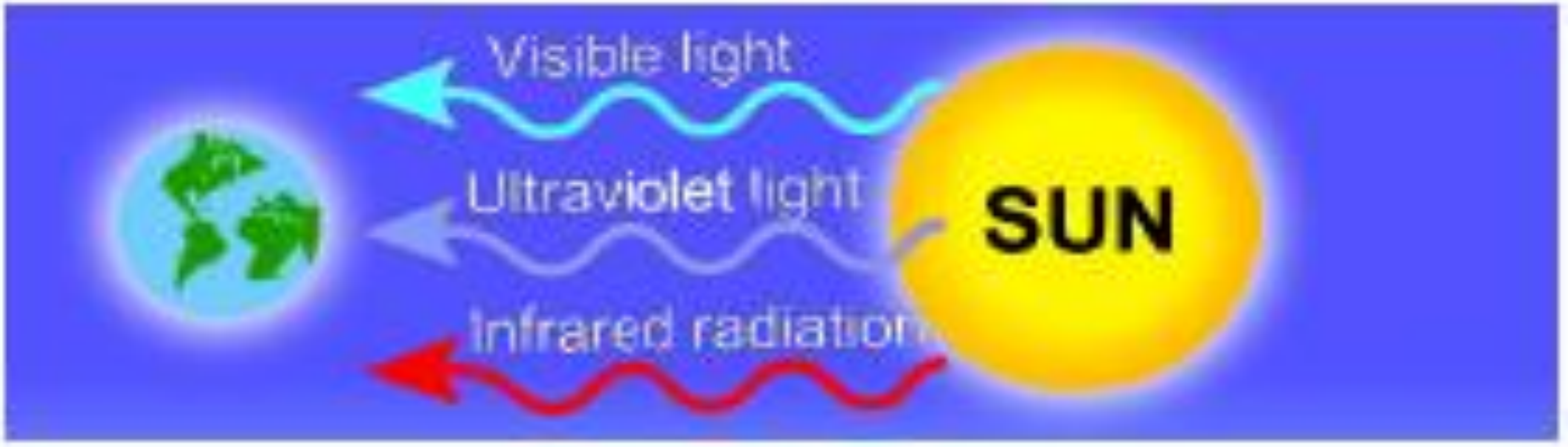
Color		Wavelength (nanometers)	Frequency (THz)
Red		650	462
Orange		600	500
Yellow		580	517
Green		530	566
Blue		470	638
Violet		400	750

Speed of Light

Speed of light
3×10^8 m/sec → $c = f\lambda$

Wavelength (m) → λ

Frequency (Hz) → f

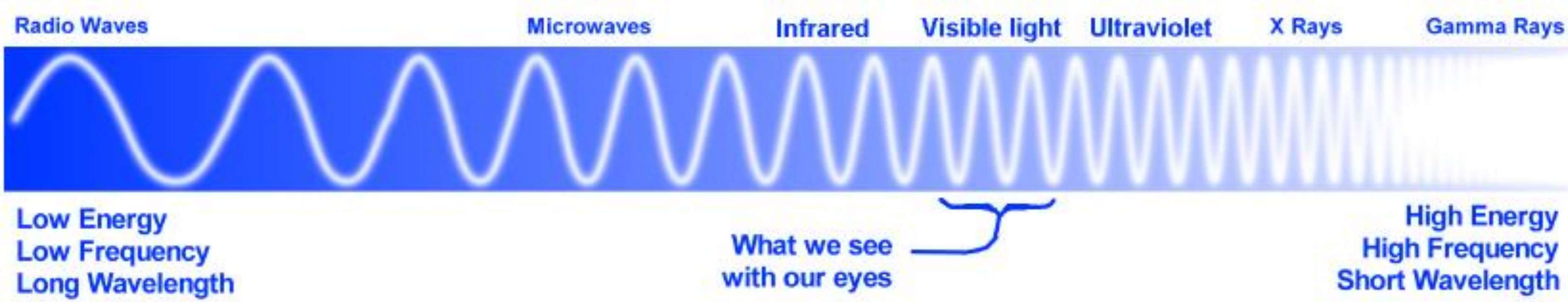


Calculate wavelength

- Calculate the wavelength in air of blue-green light that has a frequency of 600×10^{12} Hz.
- Solution – $c = f\lambda \Rightarrow \lambda = c / f$

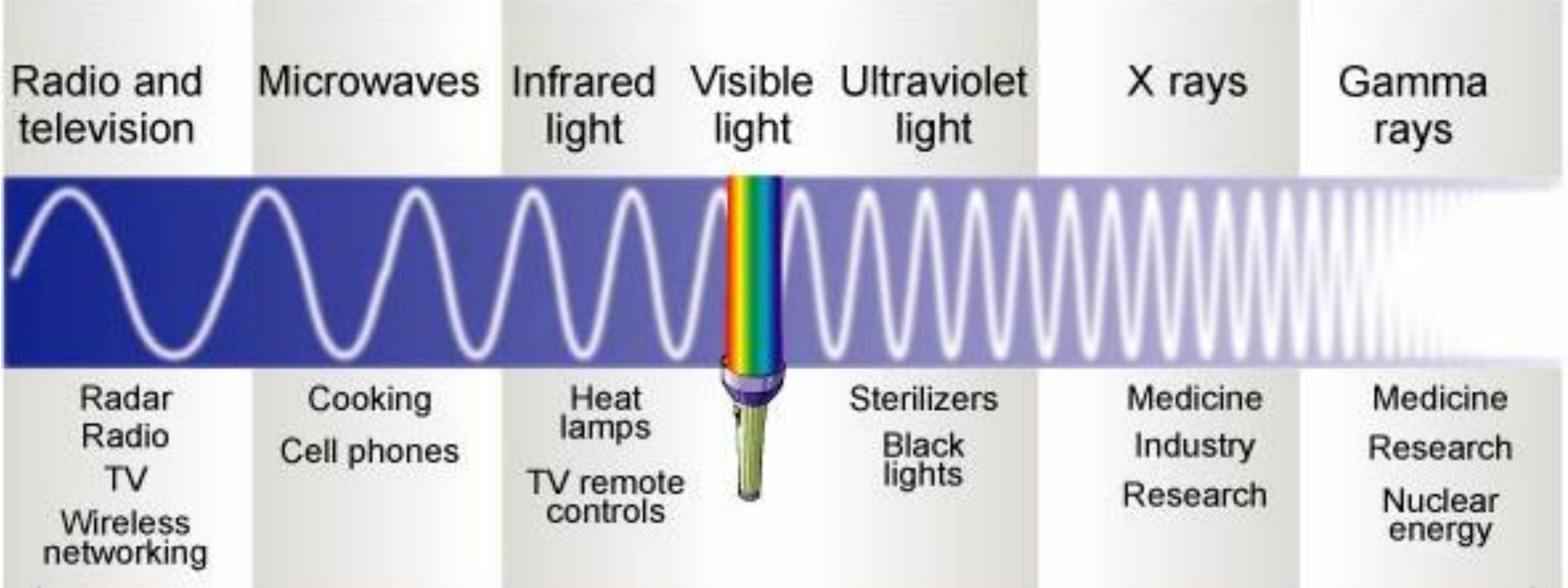
$$\lambda = \frac{3\times10^{8}}{600\times10^{12}}, \Rightarrow \lambda = 5\times10^{-7}\,m$$

$$\lambda = 500\,nm$$



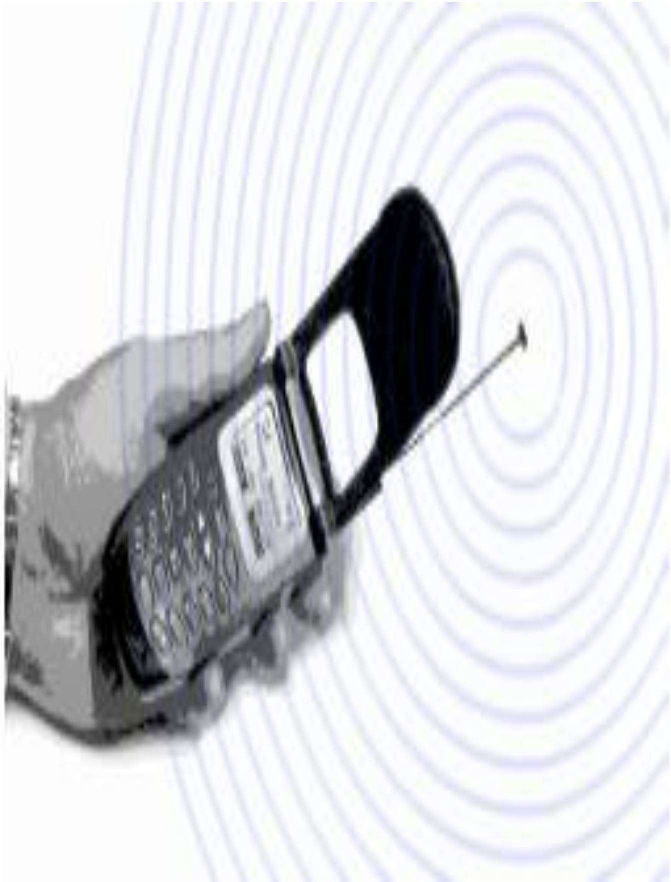
Waves of the electromagnetic spectrum

- **Visible light is a small part of the energy range of electromagnetic waves.**
- **The whole range is called the electromagnetic spectrum and visible light is in the middle of it.**



Waves of the electromagnetic spectrum

- **Radio waves are on the low-frequency end of the spectrum.**
- **Microwaves range in length from approx. 30 cm (about 12 inches) to about 1 mm.**
- **The infrared (or IR) region of the electromagnetic spectrum lies between microwaves and visible light.**

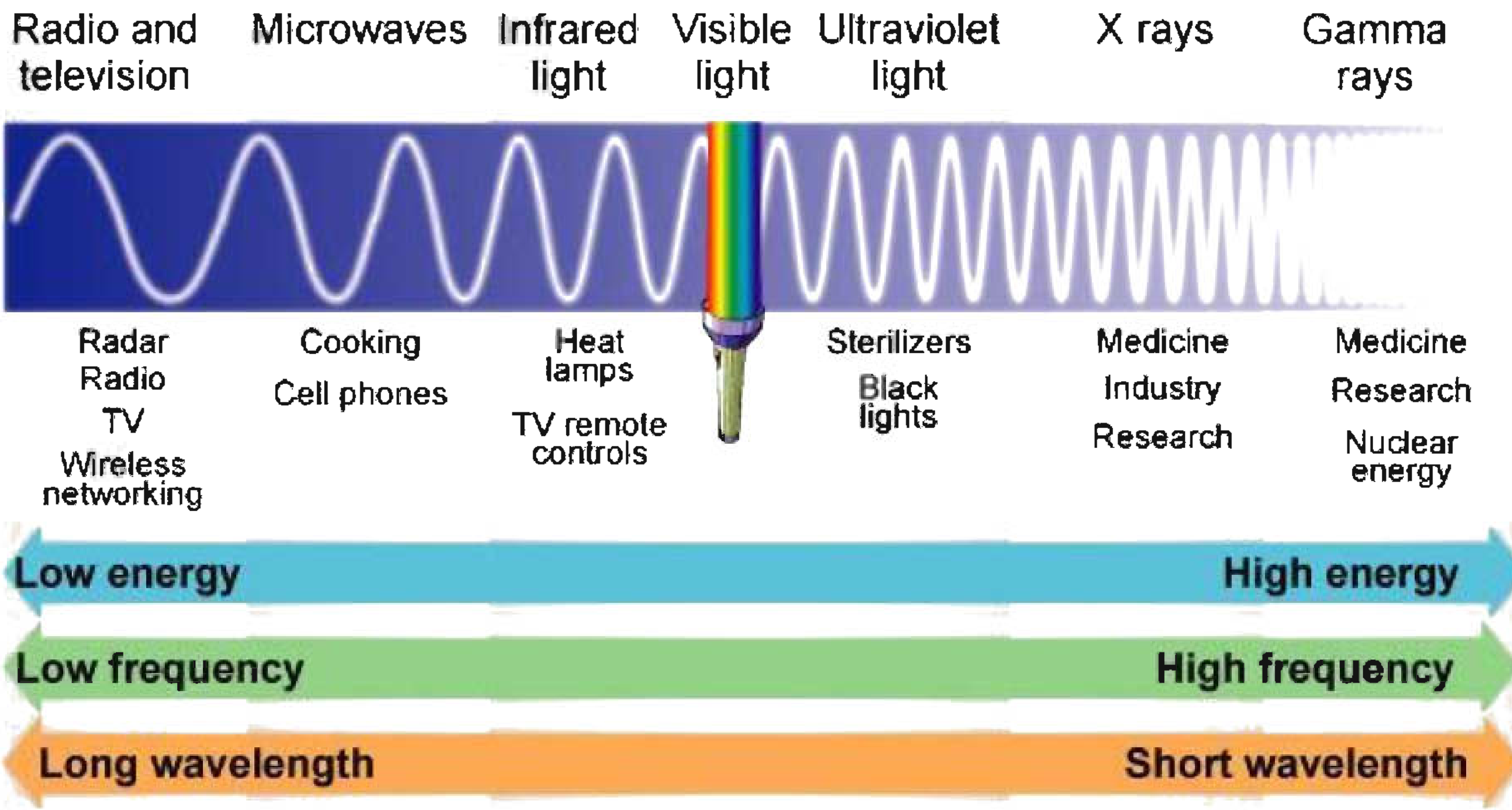


Waves of the electromagnetic spectrum

- **Ultraviolet radiation** has a range of wavelengths from 400 down to about 10 nm.
- **X-rays** are high-frequency waves that have great penetrating power and are used extensively in medical and manufacturing applications.
- **Gamma rays** are generated in nuclear reactions.

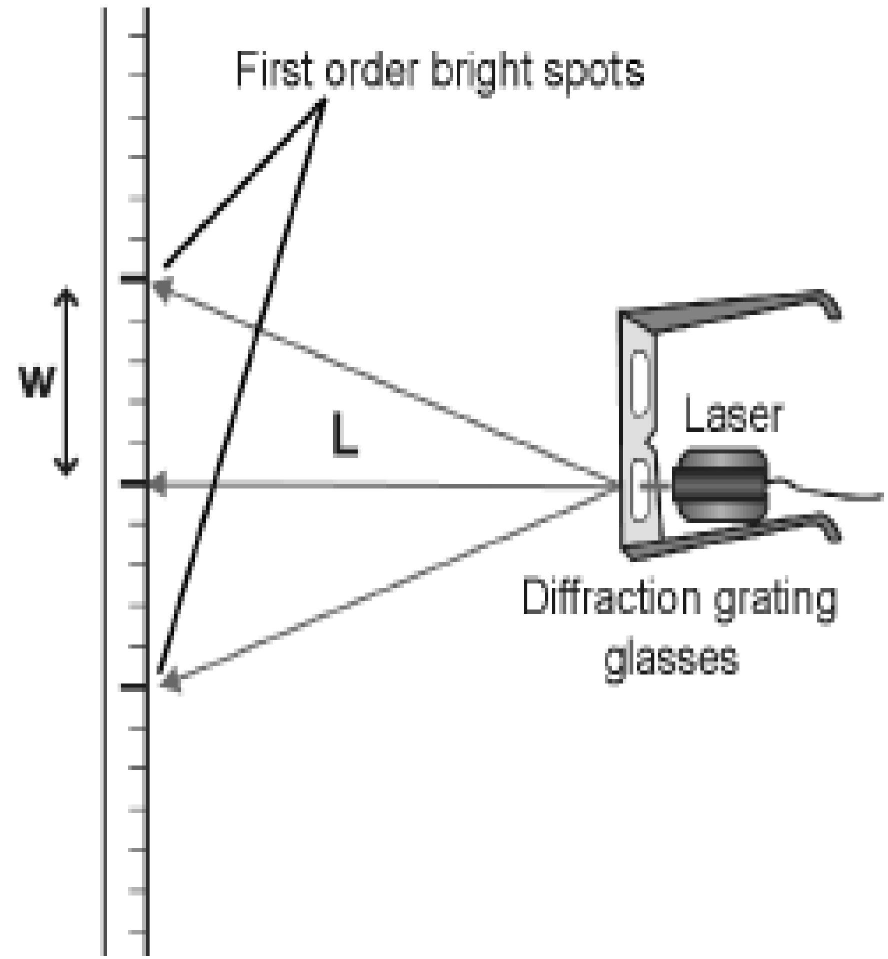
X-ray

Electromagnetic Spectrum



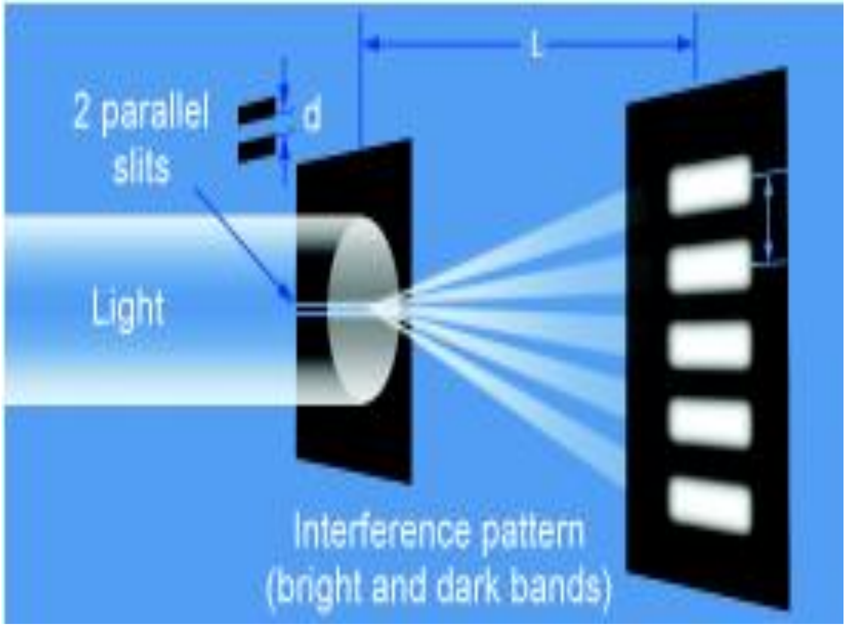
Interference, Diffraction, and Polarization

What are some ways light behaves like a wave?



Interference, Diffraction, and Polarization

- **In 1807, Thomas Young (1773-1829) did the most convincing experiment demonstrating that light is a wave.**
- **A beam of light fell on a pair of parallel, very thin slits in a piece of metal.**
- **After passing through the slits, the light fell on a screen.**



- **A pattern of alternating bright and dark bands formed is called an interference pattern.**

INTRODUCTION TO INTERFERENCE

- **When two or more sets of waves pass through the same medium, they will cross each other. These waves are not aware of the presence of each other. So the effects produced by one wave are independent of the effects due to the other. The behaviour of these two sets of waves is governed by a universal principle known as " The Principle of Superposition" which states that the net displacement at a point where two different waves are incident in the vector sum of component displacement.**
- **Any wave motion in which the amplitudes of two waves combine will show Interference.**

INTRODUCTION TO INTERFERENCE

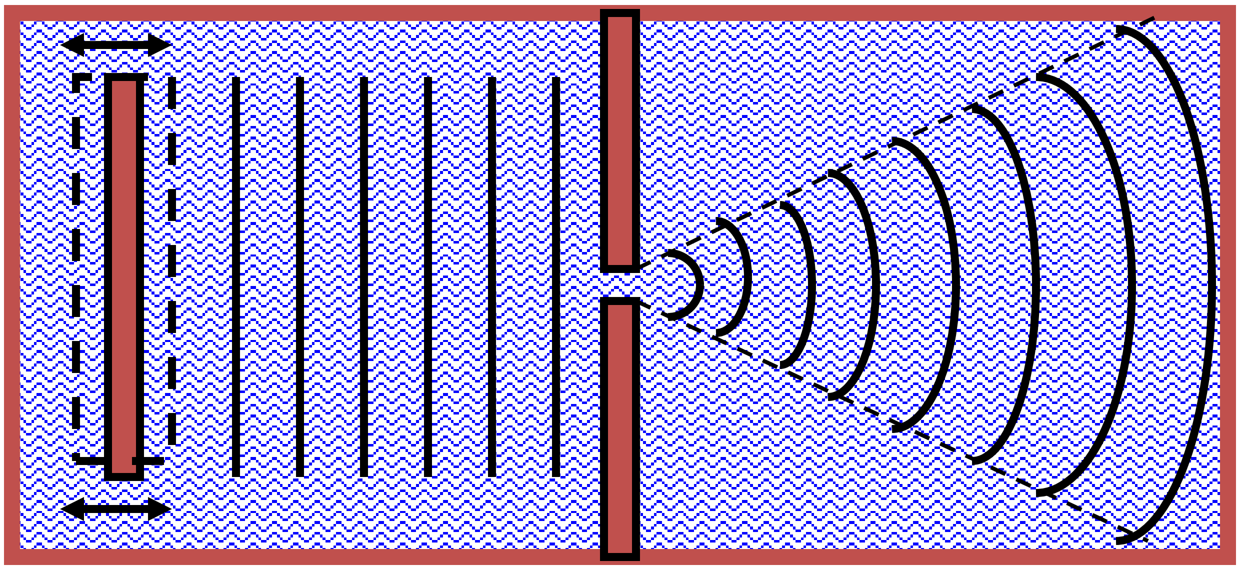
- During interference, energy and displacement are redistributed. At some points, displacement and energy become maximum and at other points displacement and energy become minimum.

- This modification in the distribution of light energy got by the superposition of two or more waves is called interference.

- TYPES OF INTERFERENCE
- Constructive Interference
- Destructive Interference

Water Waves

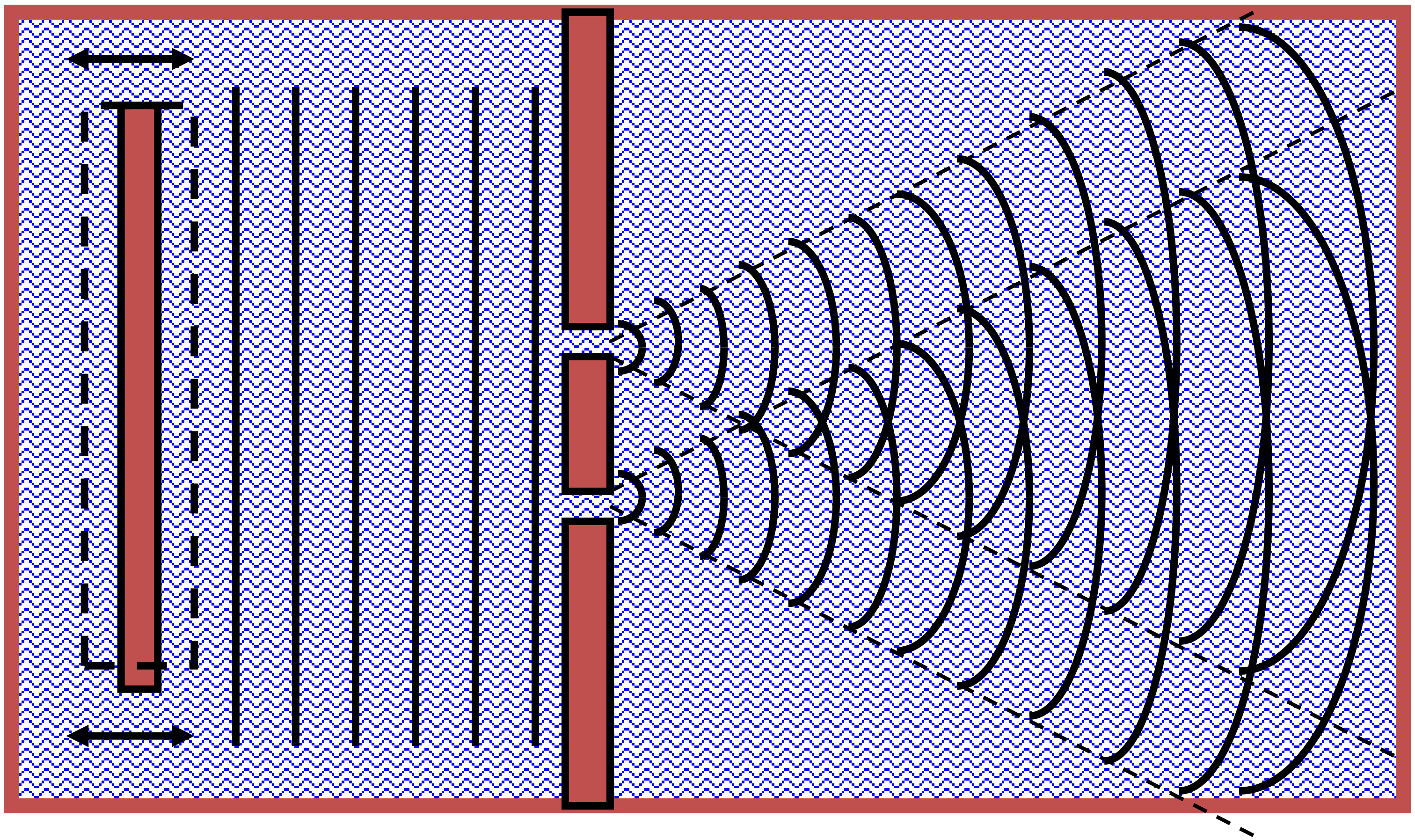
A wave generator sends periodic water waves into a barrier with a small gap, as shown below.



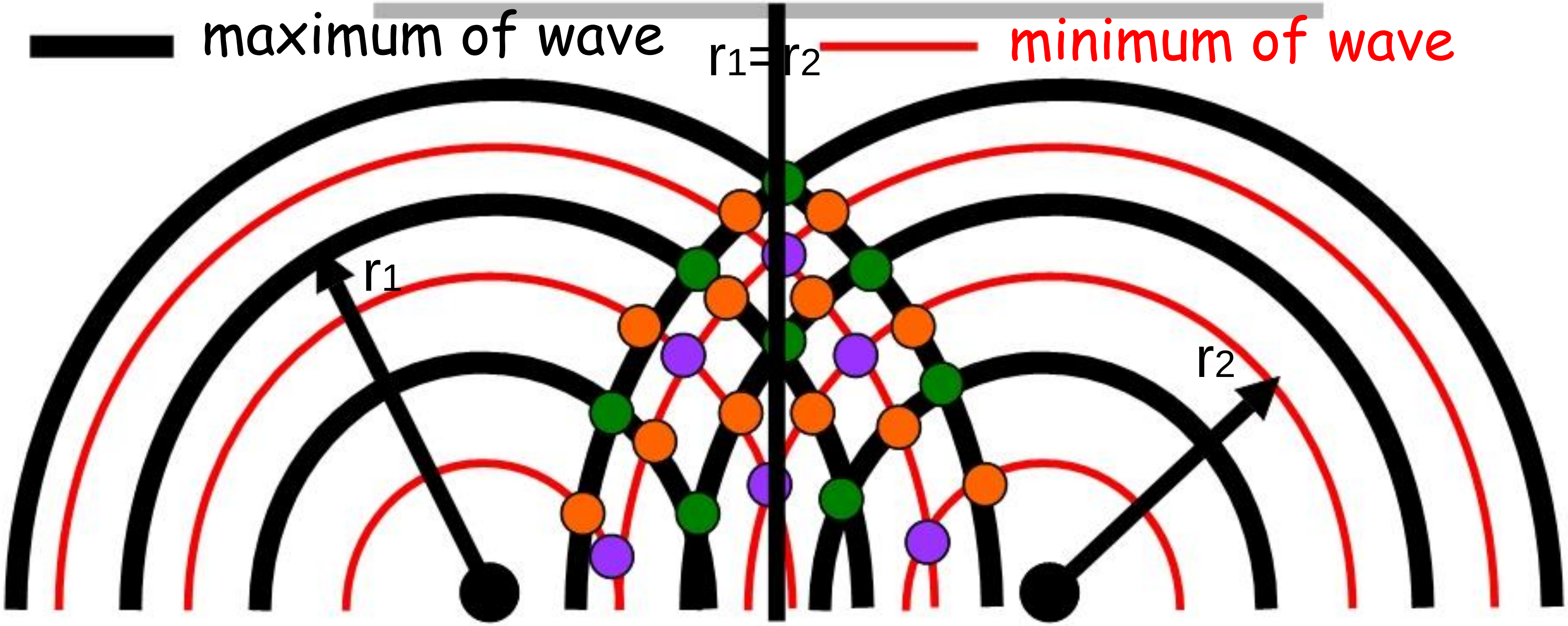
A new set of waves is observed emerging from the gap to the wall.

Interference of Water Waves

An interference pattern is set up by water waves leaving two slits at the same instant.



Interference in spherical waves

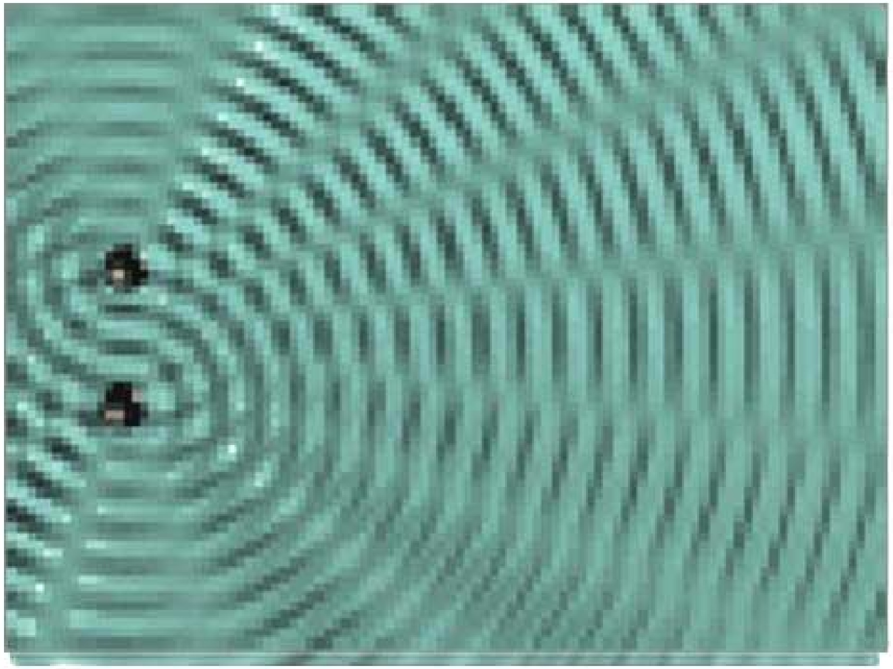


positive constructive interference

negative constructive interference

destructive interference

if $r_2 - r_1 = n\lambda$ then constructive interference occurs if $r_2 - r_1 = (n + \frac{1}{2})\lambda$ the destructive interference occurs



light as waves

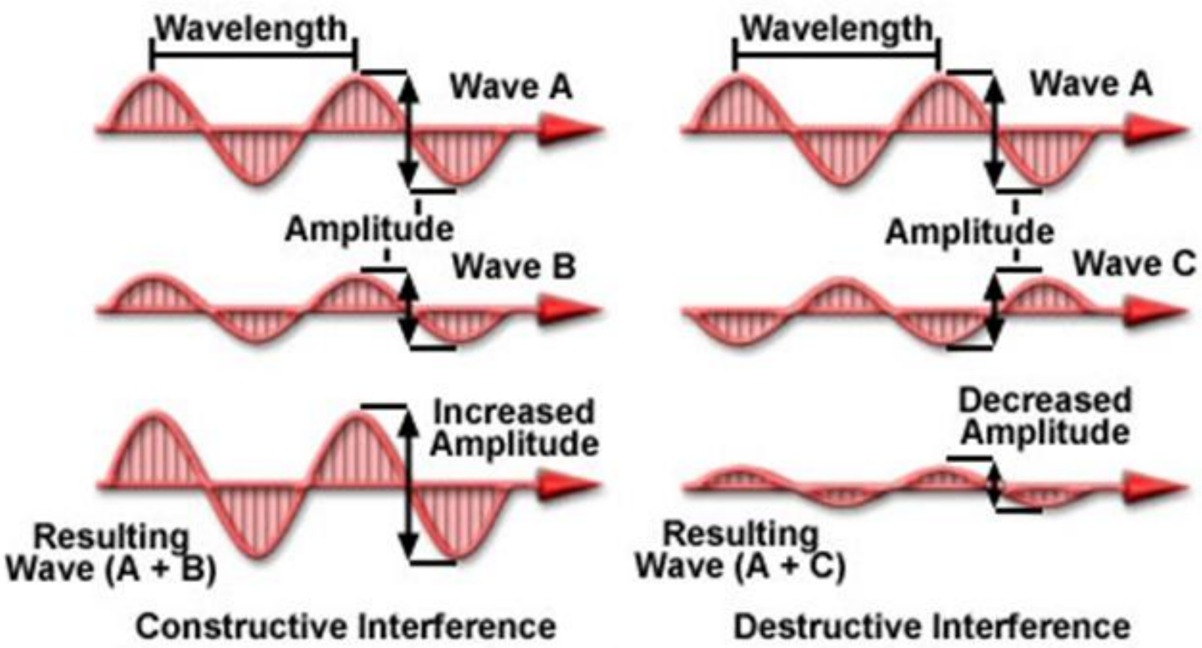


Figure 4

it works the same as water and sound!

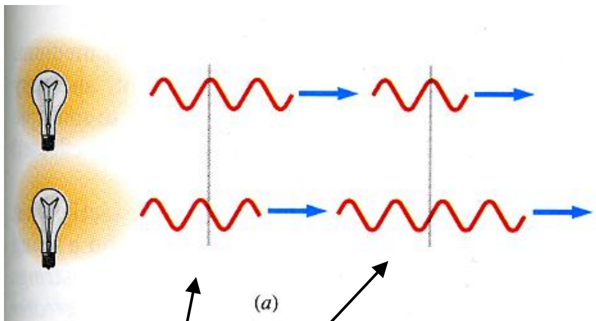
Conditions for Interference

- **If two waves have a definite phase relationship then they are coherent.**
- **Otherwise, they are incoherent (ex: two light bulbs).**
- **For Interference:**
  - **The sources must be coherent.**
  - **The sources should be monochromatic.**

Interference

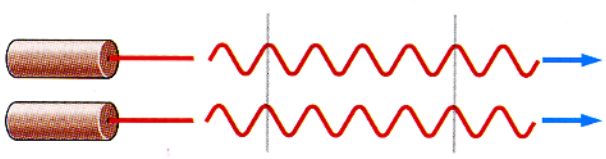
Coherence and Monochromatic

- No coherence between two light bulbs



(a)

coherence - two or more waves that maintain a constant phase relation.

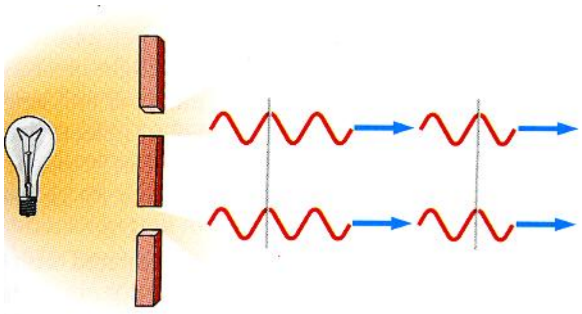


(b)

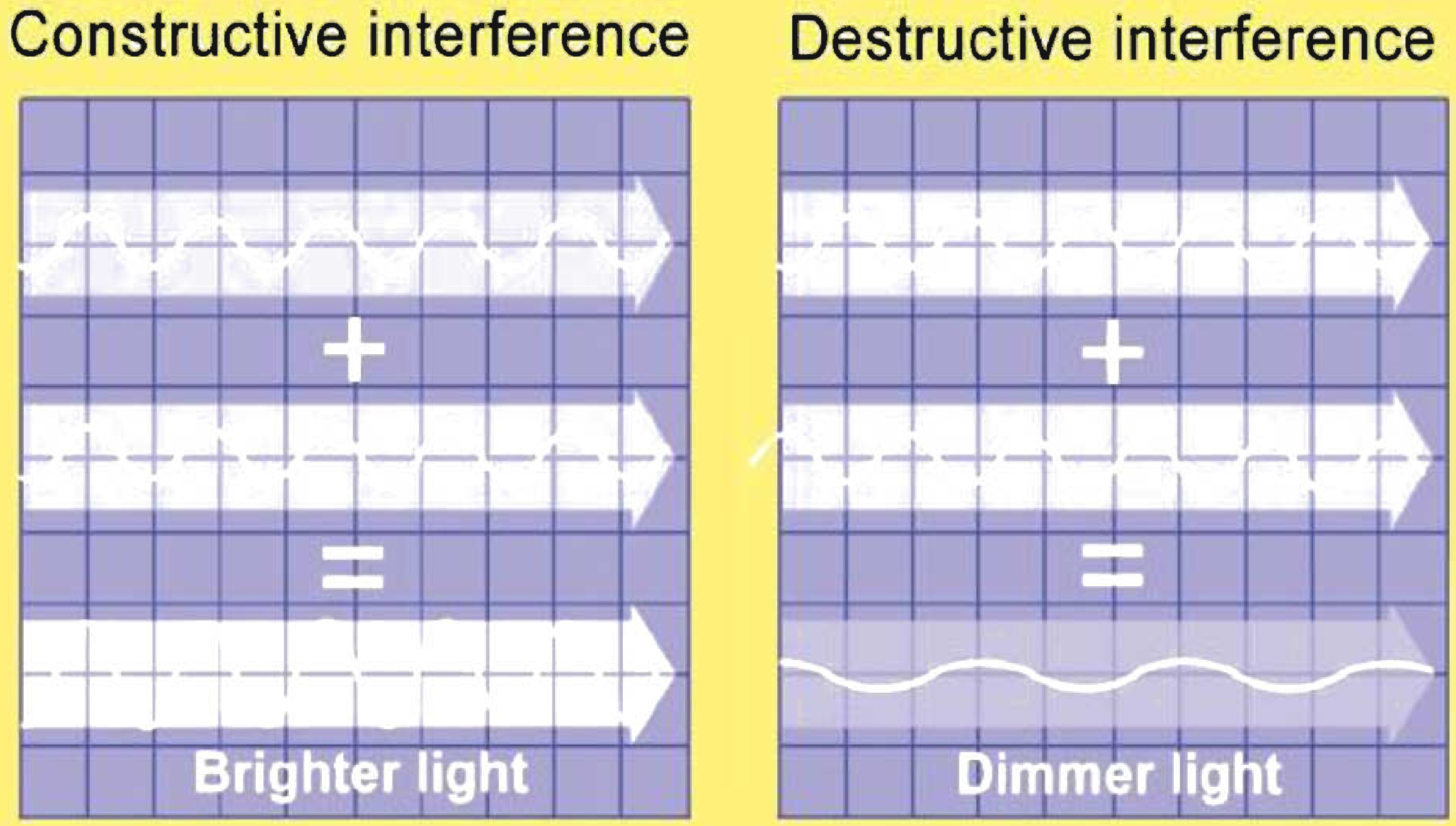
Some later time or distance

Coherence time
Coherence length

monochromatic - a wave that is composed of a single frequency. Heisenberg uncertainty relation.



The Interference of Light Waves



For Constructive Interference:

The waves must arrive to the point of study in phase.

So their path difference must be integral multiples of the wavelength:

$\Delta L = n\lambda$

$n = 0, 1, 2, 3, \ldots\ldots\ldots$

For destructive interference:

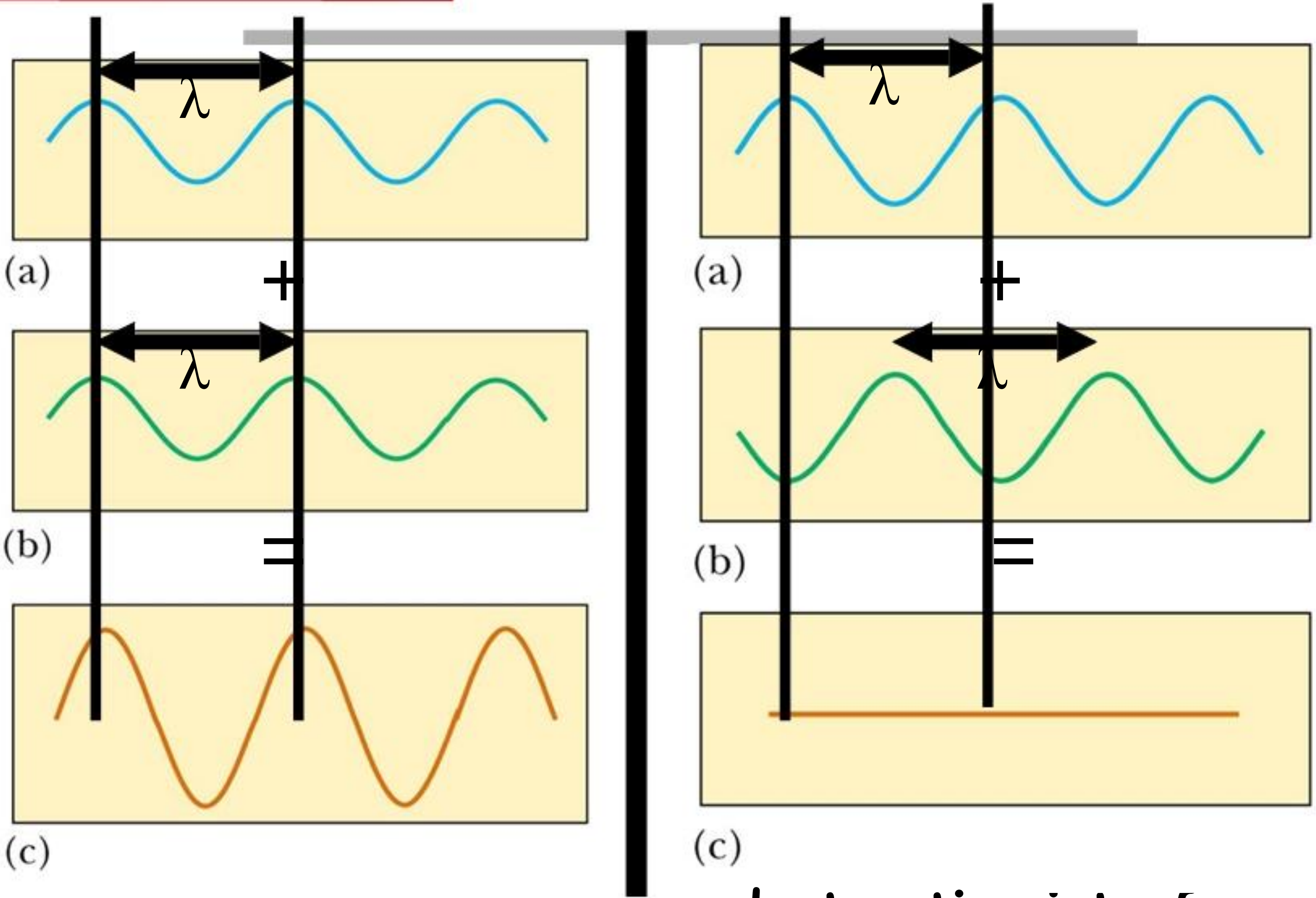
the waves must arrive to the point of study out of phase.

So the path difference must be an odd multiple of $\lambda/2$:

$\Delta L = n\ \lambda$

m=1/2,3/2,5/2,....

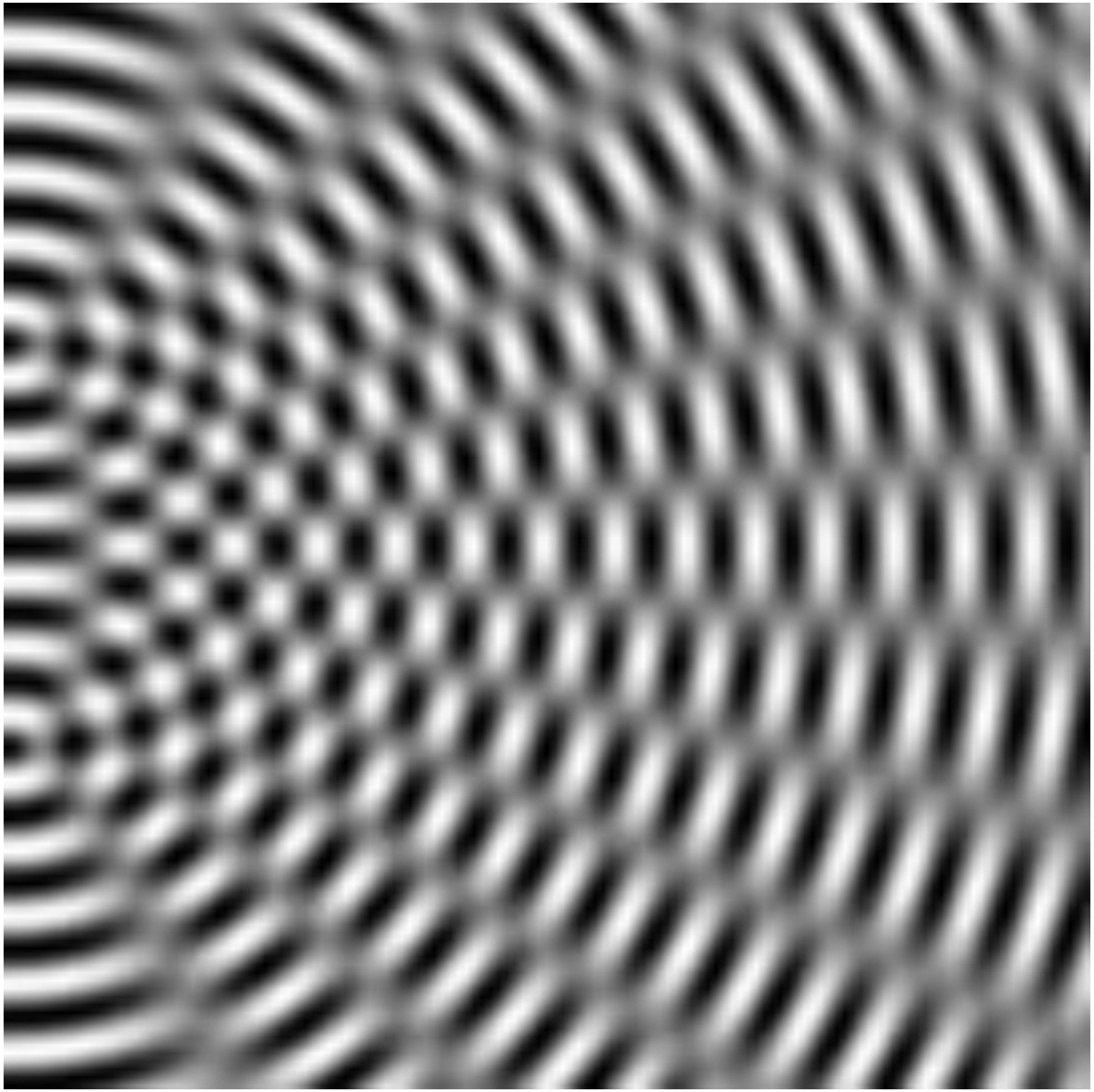
demo: interference



constructive interference
waves in phase

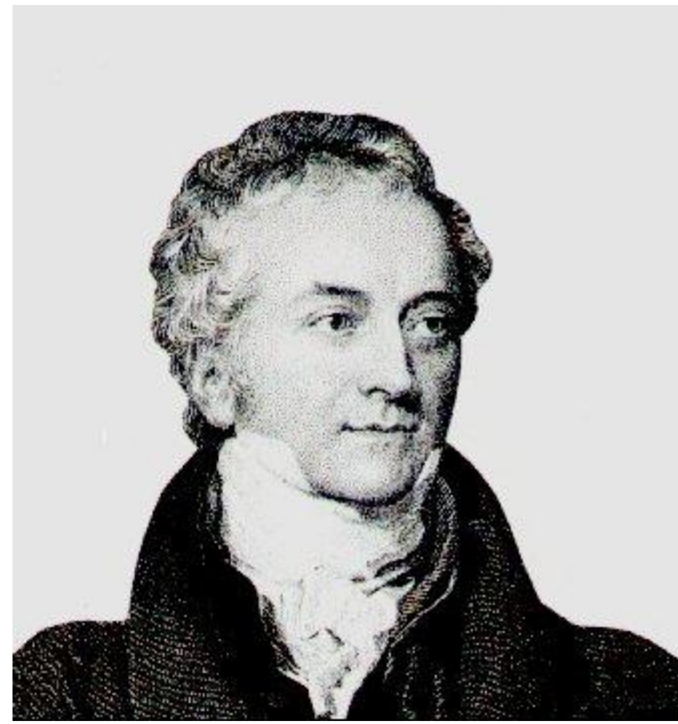
destructive interference
waves ½λ out of phase

Two Waves Interfering



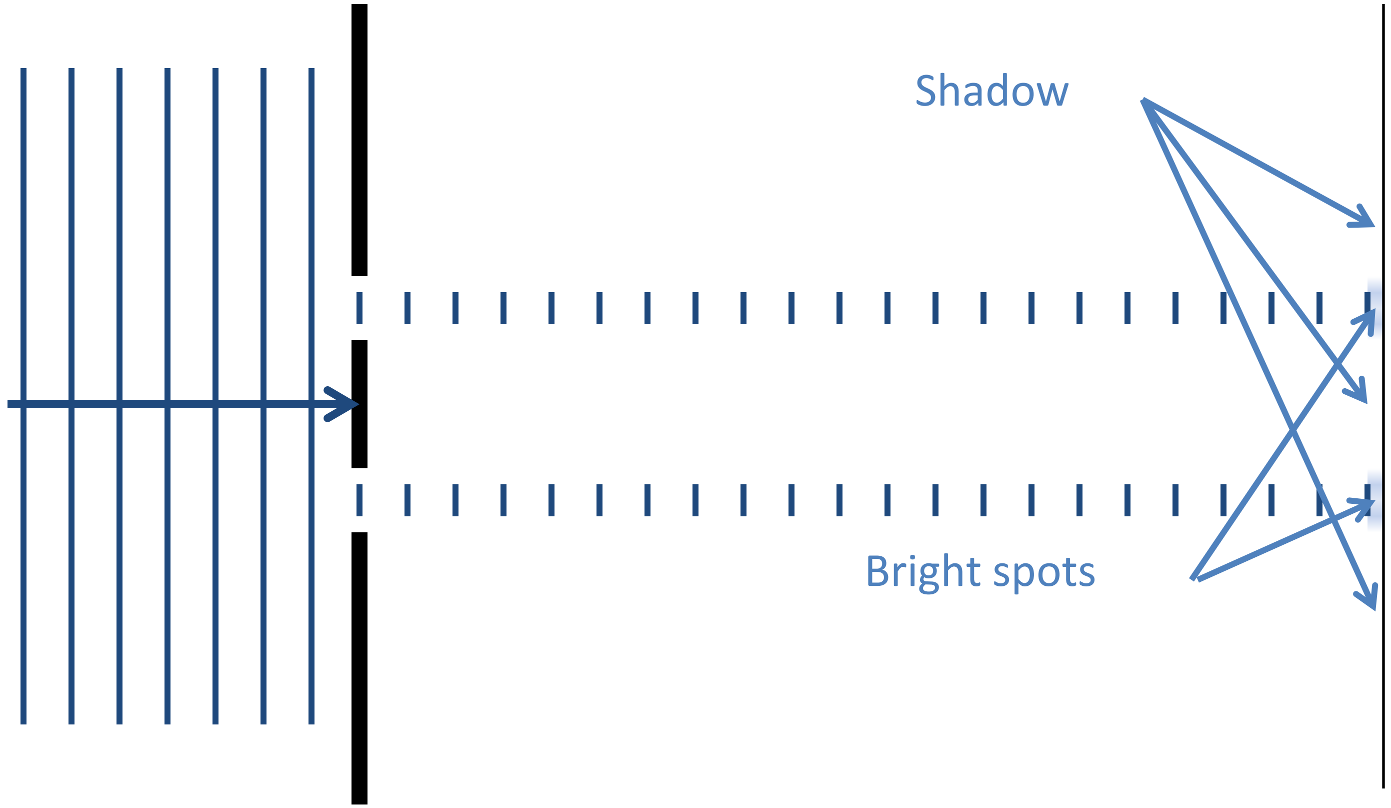
Thomas Young’s Double Slit Interference Experiment

- Showed an interference pattern
- Measured the wavelength of the light



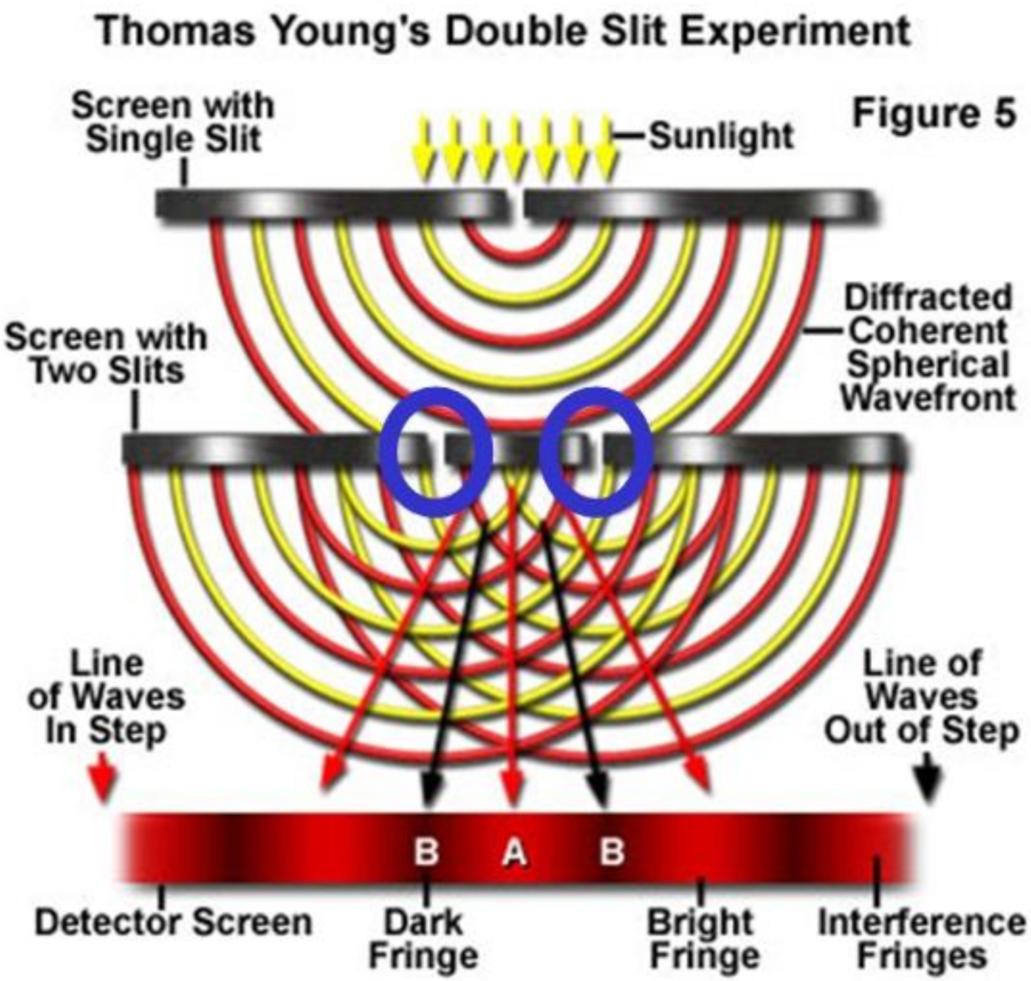
Young's double slit/rays

Monochromatic light travels through 2 slits onto a screen
What pattern emerges on the screen?



This is <u>not</u> what is actually seen!

double slit experiment

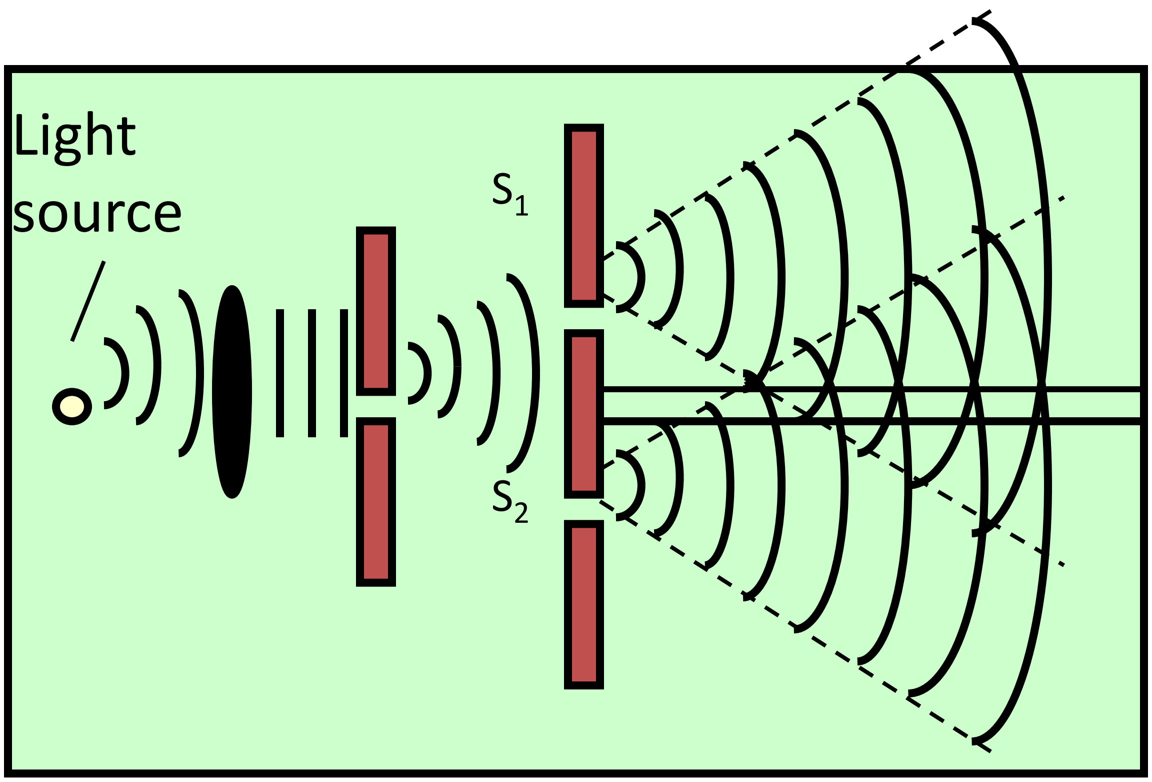


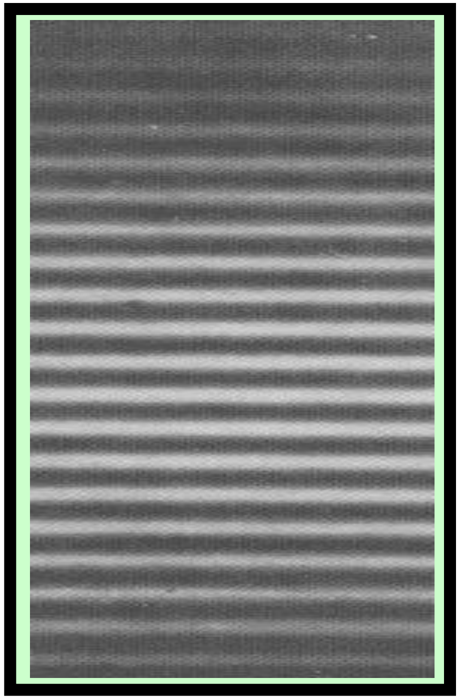
- the light from the two sources is incoherent (fixed phase with respect to each other
- in this case, there is no phase shift between the two sources

- the two sources of light must have identical wave lengths

Young’s Experiment

In Young’s experiment, light from a monochromatic source falls on two slits, setting up an interference pattern analogous to that with water waves.

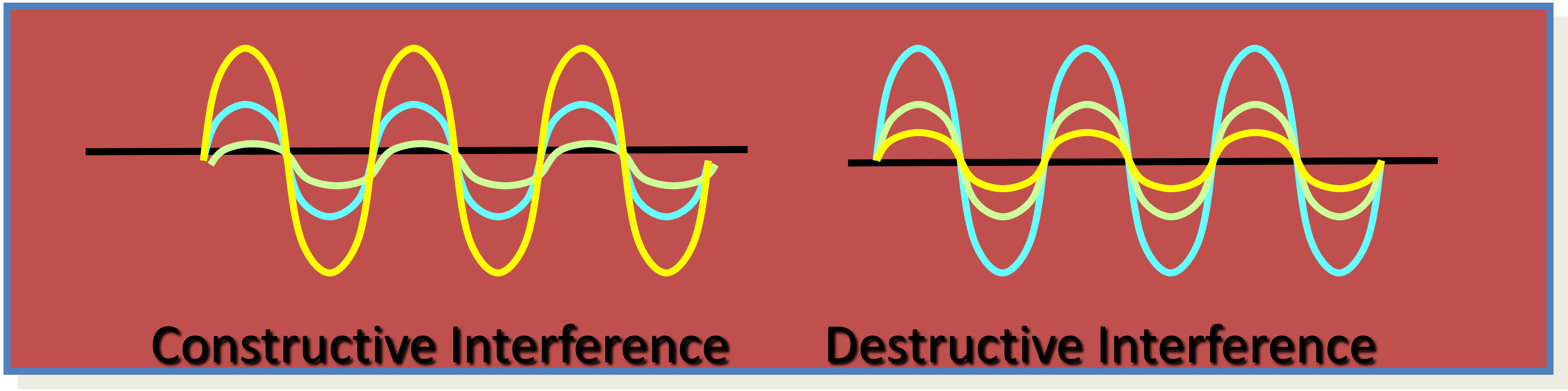




The Superposition Principle

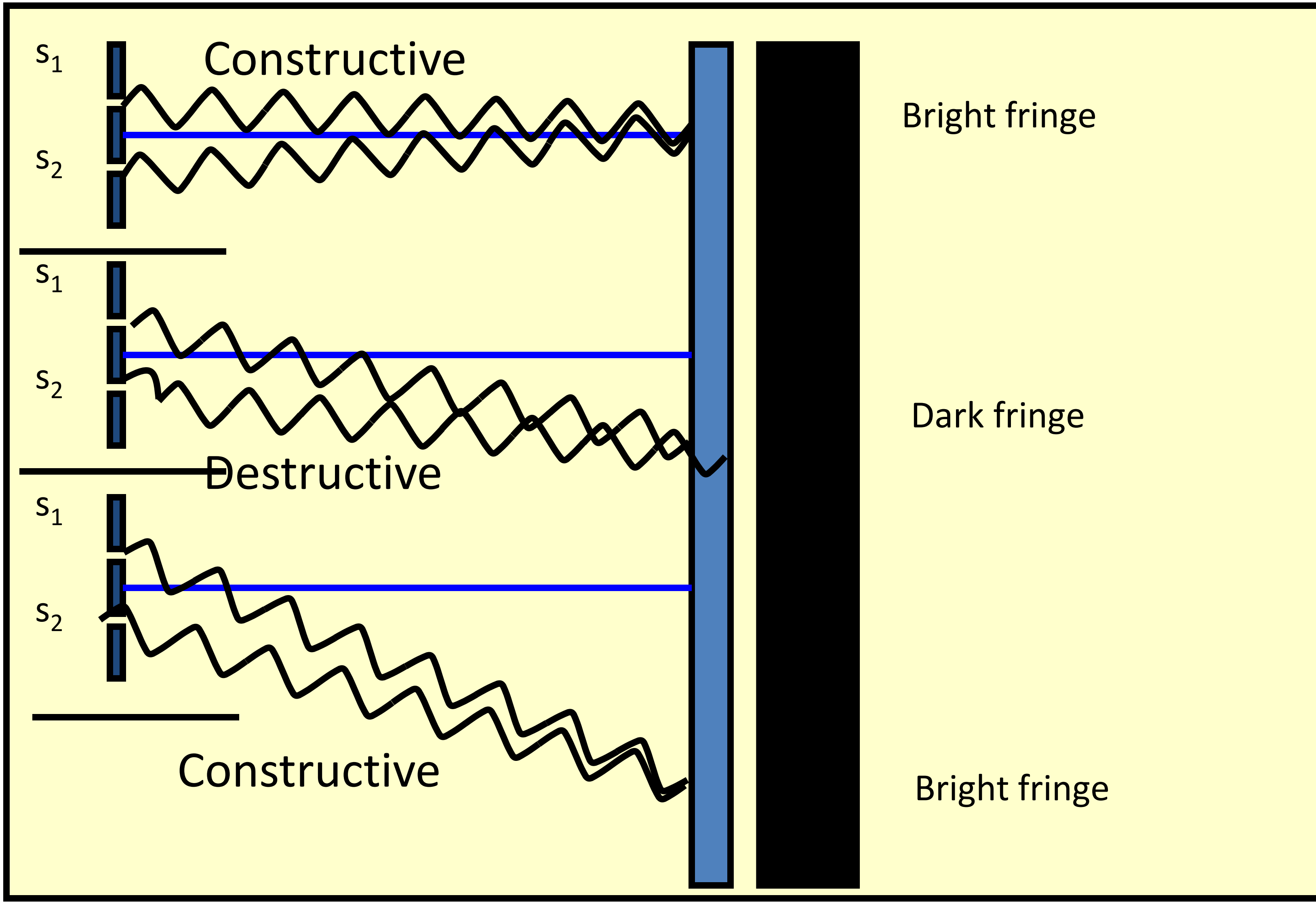
- The resultant displacement of two simultaneous waves (blue and green) is the algebraic sum of the two displacements.

- **The composite wave is shown in yellow.**



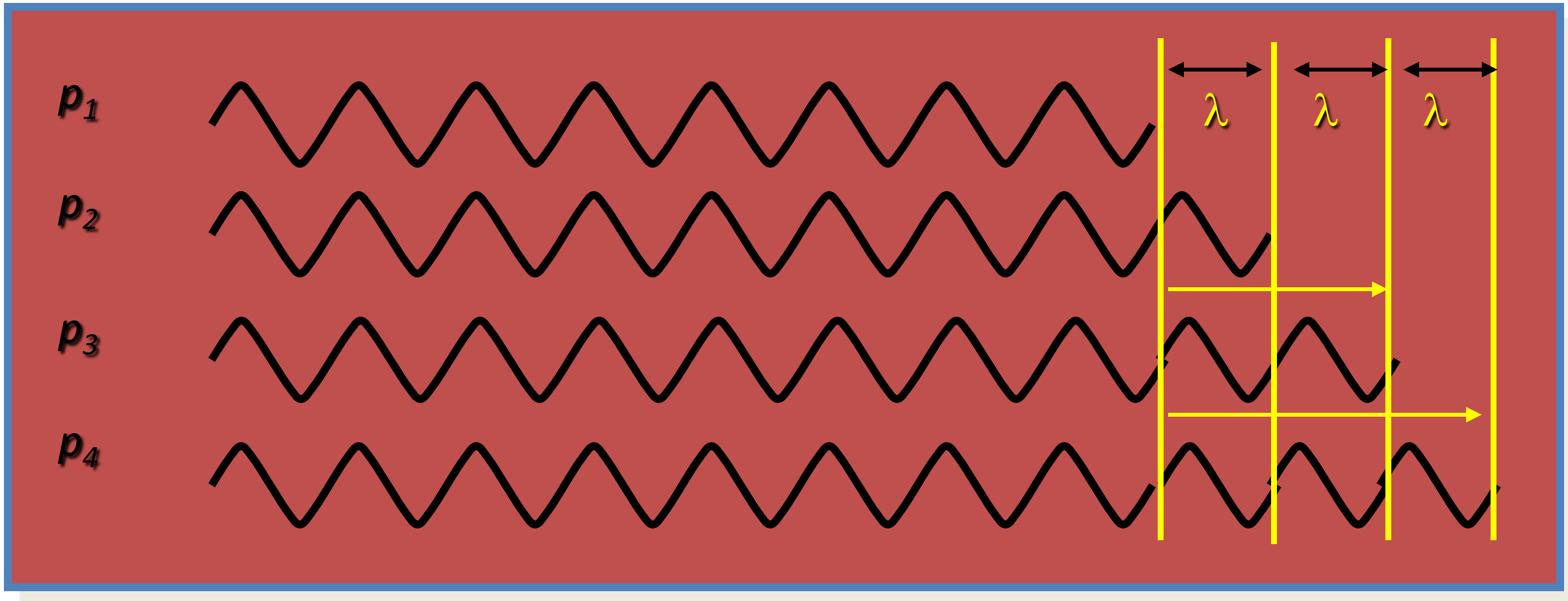
The superposition of two coherent light waves results in light and dark fringes on a screen.

Young's Interference Pattern



Conditions for Bright Fringes

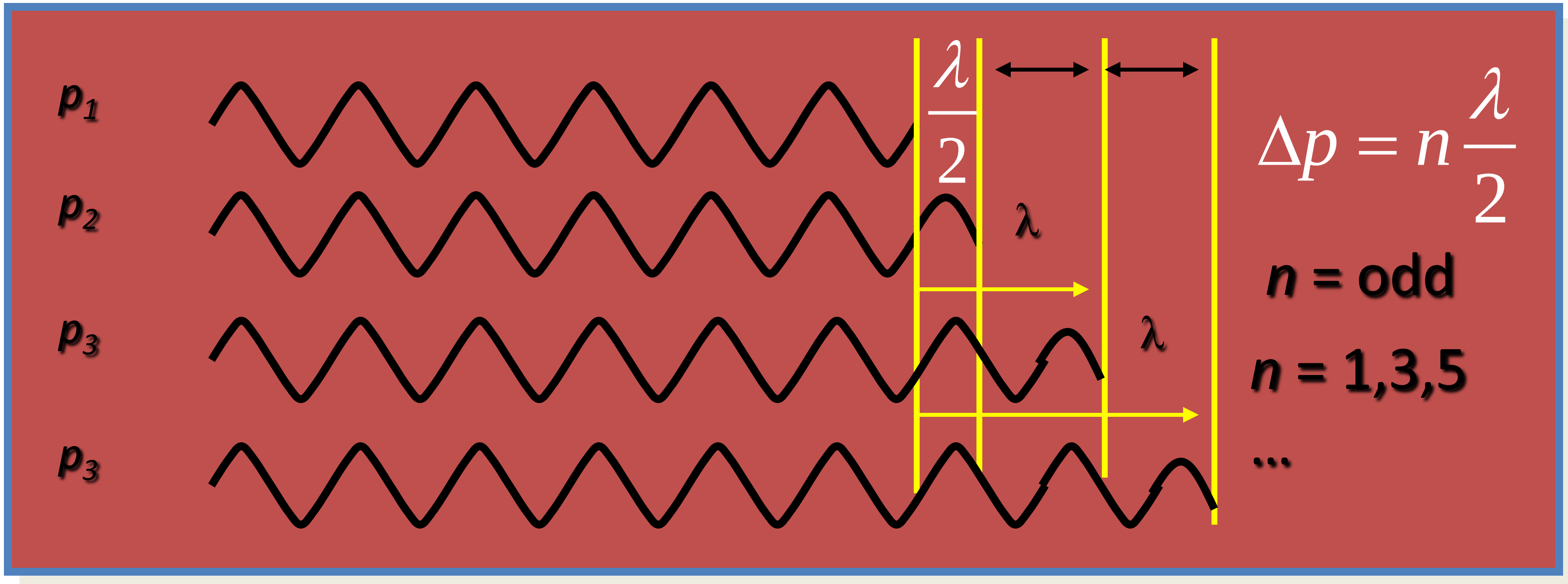
Bright fringes occur when the difference in path Δp is an integral multiple of one wave length λ.



Path difference	Bright fringes:
$\Delta p = 0, \lambda, 2\lambda, 3\lambda, \ldots$	$\Delta p = n\lambda, \quad n = 0, 1, 2, \ldots$

Conditions for Dark Fringes

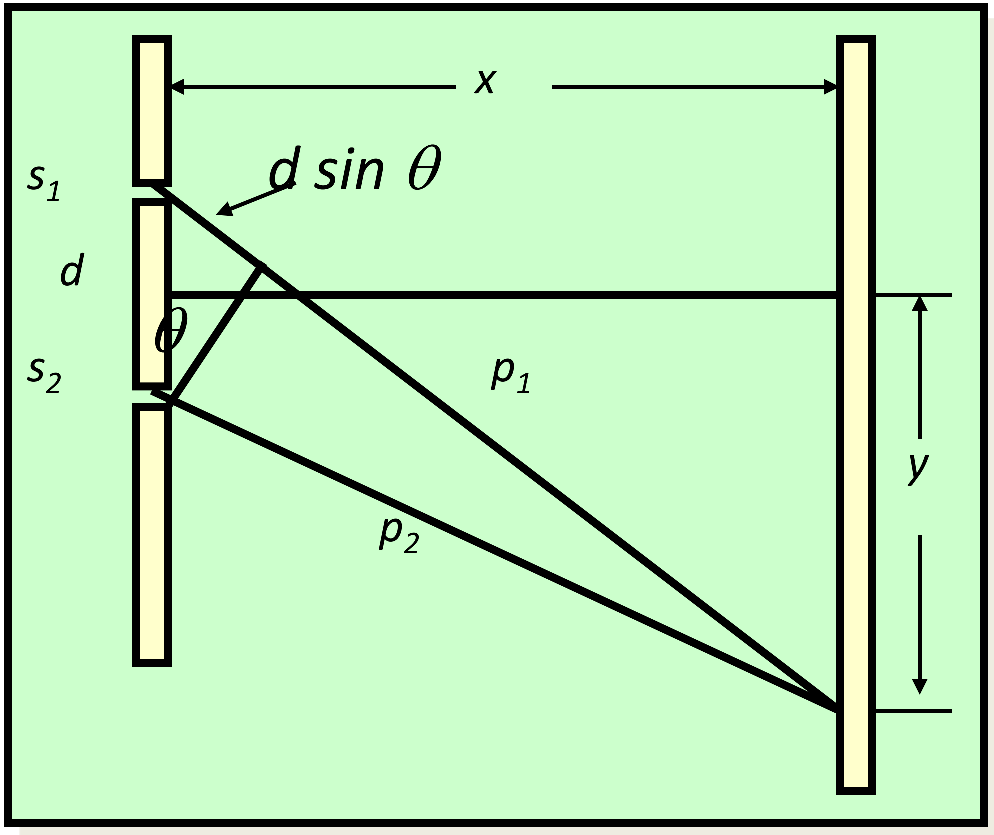
Dark fringes occur when the difference in path *Δp* is an odd multiple of one-half of a wave length λ/2.



Dark fringes:

$$\Delta p = n\frac{\lambda}{2} \qquad n = 1,\ 3,\ 5,\ 7,\ \ldots$$

Analytical Methods for Fringes



Path difference determines light and dark pattern.

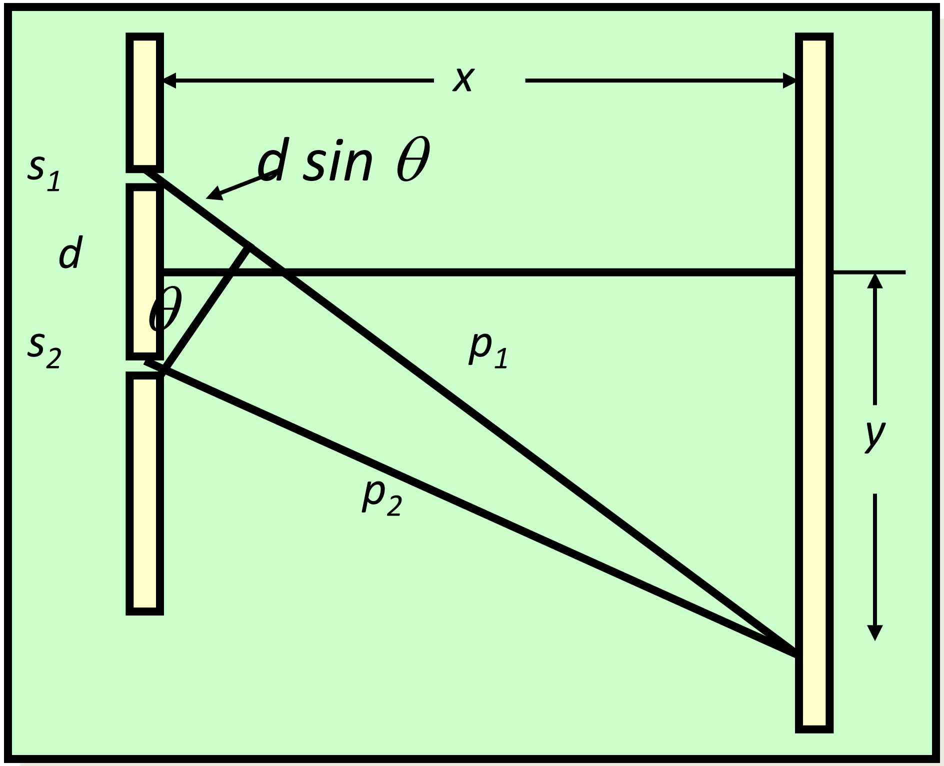
$\Delta p = p_1 - p_2$

$\Delta p = d \sin \theta$

Bright fringes: $d \sin \theta = n\lambda,\ n = 0, 1, 2, 3, \ldots$

Dark fringes: $d \sin \theta = n\lambda/2,\ n = 1, 3, 5, \ldots$

Analytical Methods (Cont.)



From geometry, we recall that:

$$\sin\theta \approx \tan\theta = \frac{y}{x}$$

So that . . .

$$d\sin\theta = \frac{y}{x}$$

Bright fringes:

$$\frac{dy}{x} = n\lambda, \quad n = 0,\ 1,\ 2,\ \ldots$$

Dark fringes:

$$\frac{dy}{x} = n\frac{\lambda}{2}, \quad n = 1,\ 3,\ 5\ldots$$

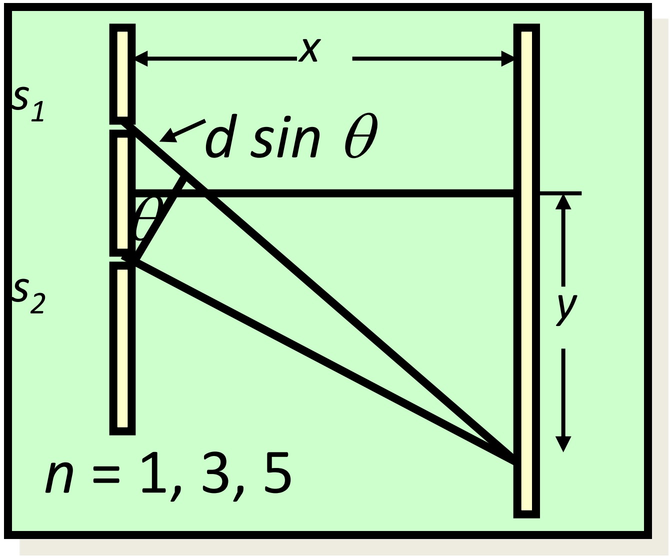
Example 1: Two slits are 0.08 mm apart, and the screen is 2 m away. How far is the third dark fringe located from the central maximum if light of wavelength 600 nm is used?

$x = 2$ m; $d = 0.08$ mm

$\lambda = 600$ nm; $y = ?$

$d \sin\theta = 5(\lambda/2)$

The third dark fringe occurs when *n = 5*



Dark fringes:

$$\frac{dy}{x} = n\frac{\lambda}{2}, \quad n = 1, 3, 5\ldots$$

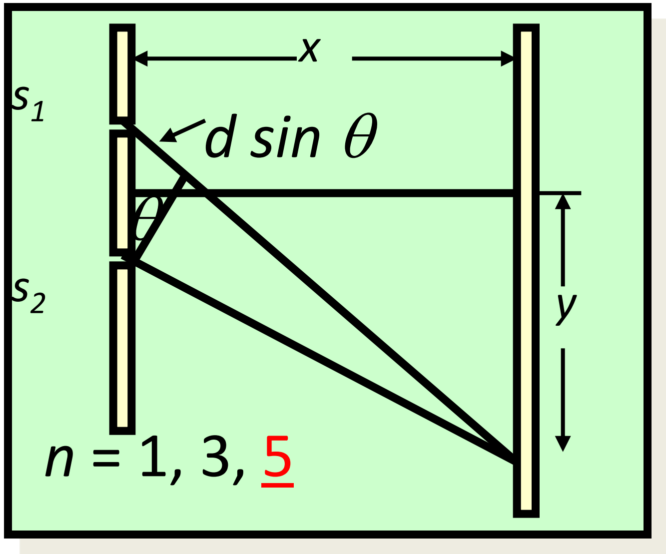
$$\frac{dy}{x} = \frac{5\lambda}{2}$$

Example 1 (Cont.): Two slits are 0.08 mm apart, and the screen is 2 m away. How far is the third dark fringe located from the central maximum if λ = 600 nm?

x = 2 m; *d* = 0.08 mm

λ = 600 nm; y = ?

$$\frac{dy}{x} = \frac{5\lambda}{2}$$

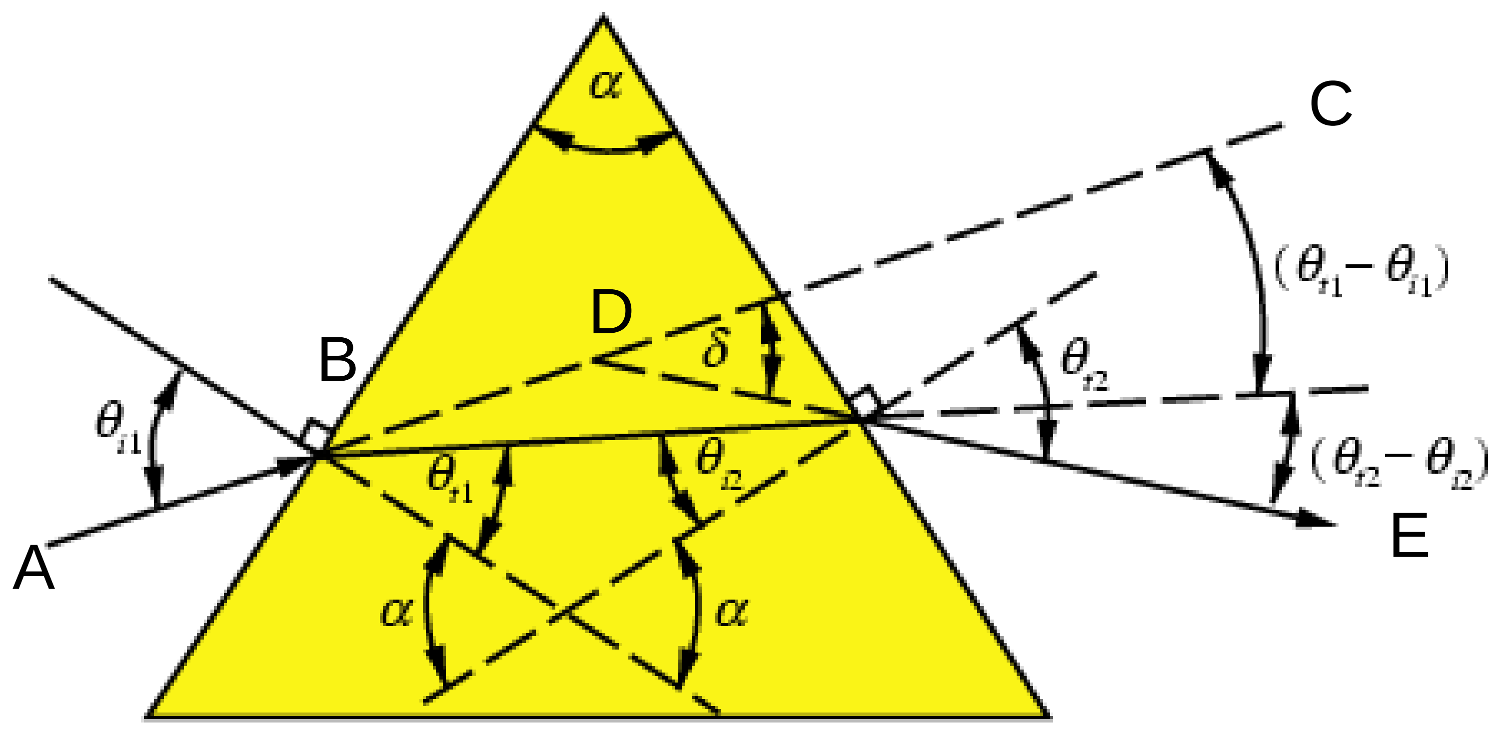


***y* = 3.75 cm**

Prism

A prism is a wedge-shaped transparent body which causes incident light to be separated by color. The separation by color occurs since different colors corresponding to different wavelengths.

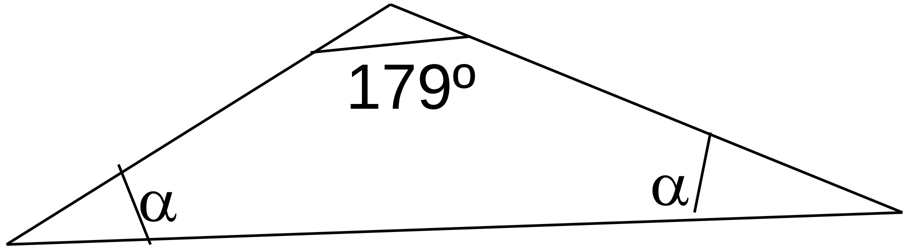
It is a device used to refract light, reflect it or break it up (to disperse it) into its constituent spectral colours.

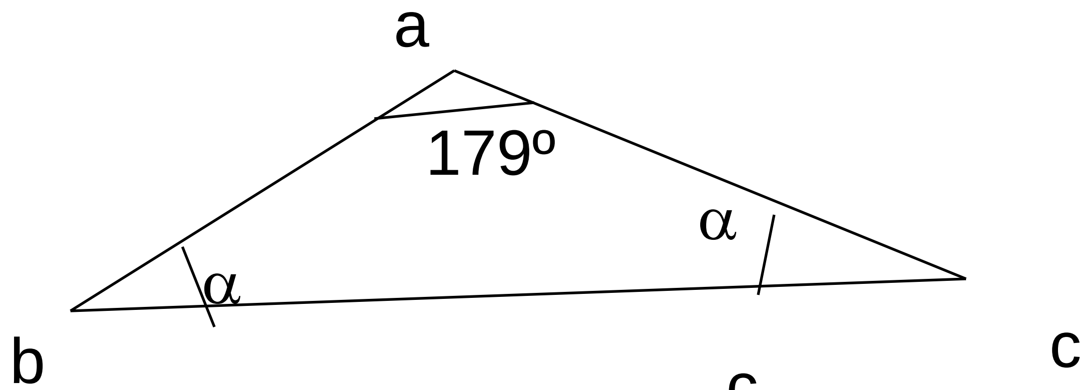


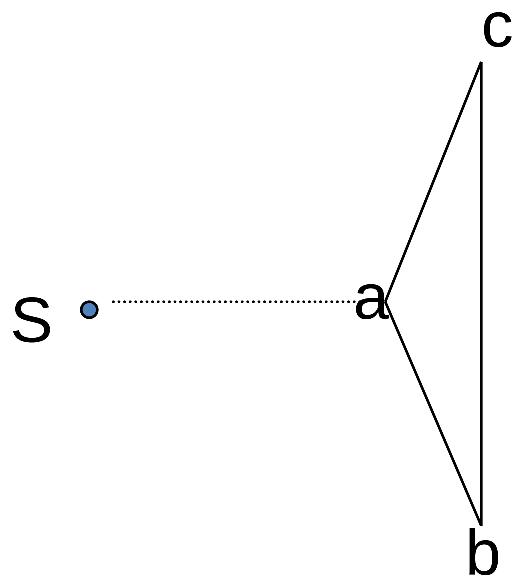
$$\delta = (\mu - 1)\alpha$$

Biprism

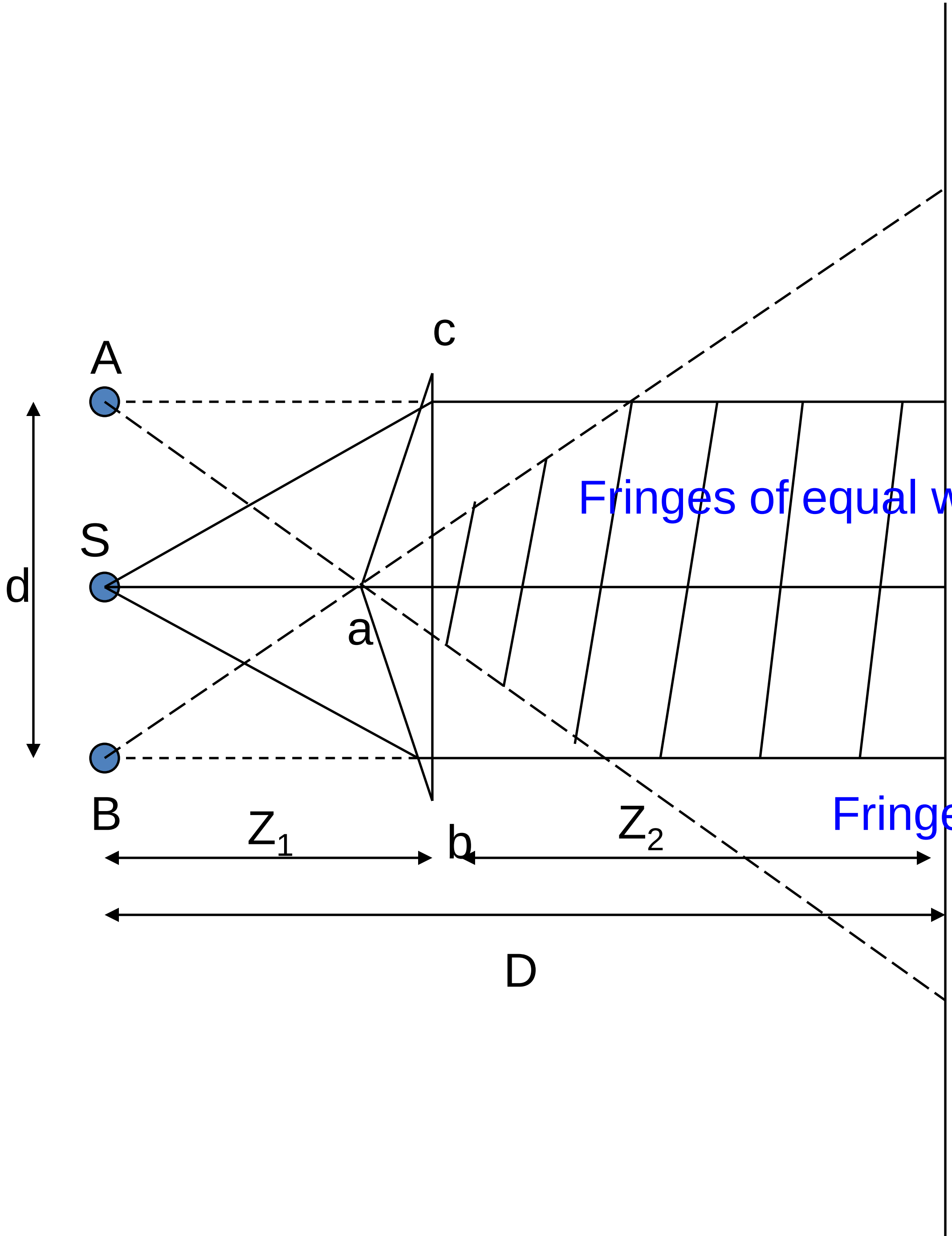
It consists of two thin acute angled <u>prisms</u> joined at the bases. It is constructed as a single prism of obtuse angle of 179º. The acute angle α on both side is about 30´. A portion of the incident light is <u>refracted</u> downward and a portion upward.







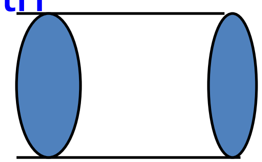
The prism is placed with the refracting edge parallel to the line
Source S such that Sa is normal to the face bc of prism.



When light incident from S on the lower portion of prism It bents upwards and appears to come from virtual source B. Similarly light from S incident on the upper
portion of Prism bents downwards appear to come from A.

So A and B are two virtual coherent sources.

AB = d



C is the screen

Distance between source and eyepiece = D

Interference fringes of equal width will be occur between EF portion of the screen. Beyond EF portion fringes of large width will be produced.

Since C is equidistant from A and B so at C maximum fringe intensity will occur.
On both sides of C alternate bright and dark fringes will appear.

As we know

$$\beta = \frac{\lambda D}{d}$$

So position of bright fringes from C = $\frac{n\lambda D}{d}$

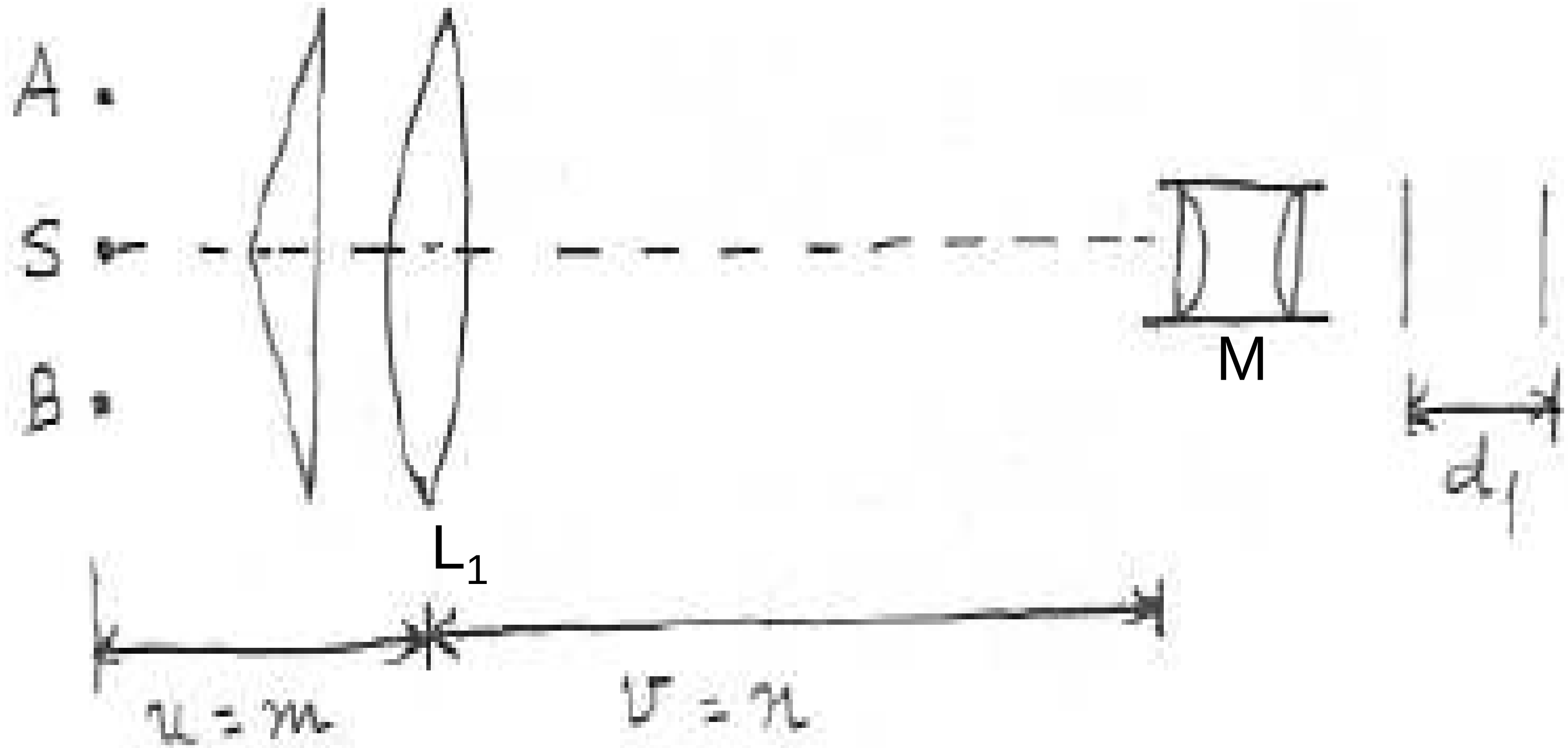
Position of dark fringes from C = $\frac{(2n+1)\lambda D}{2d}$

n = 0,1,2,3….

So the wavelength of light will be

$$\lambda = \frac{\beta d}{D}$$

Determination of the distance between the two sources (d)



A convex lens (L_1) is placed between the prism and eyepiece (M), such that the image of the virtual sources A and B are seen in the field of view of the eyepiece.

Suppose the distance between the images of A and B as seen by the eyepiece is d_1.

So ,
$$\frac{d_1}{d} = \frac{v}{u} = \frac{n}{m}$$

Eyepiece is moved horizontally to determine the fringe width.

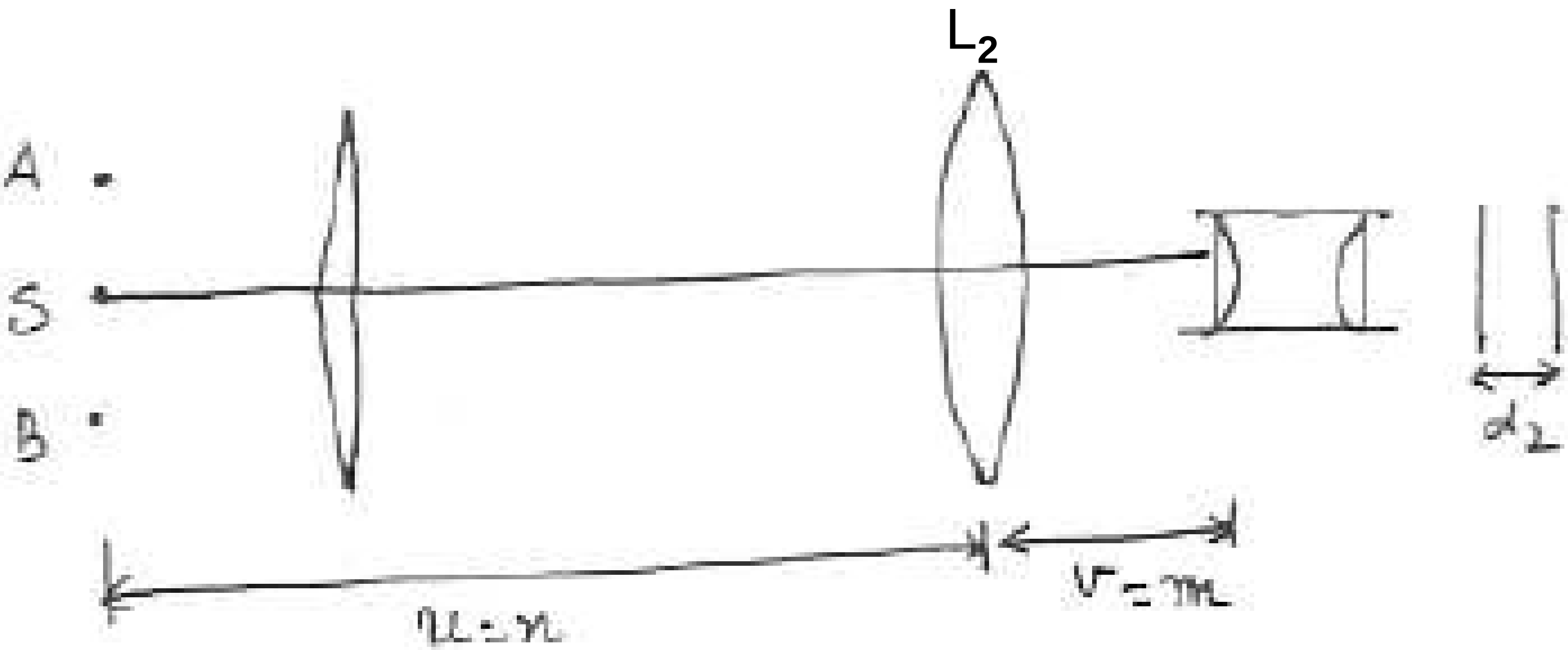
Suppose for crossing 20 bright fringes from the field of view, the Eyepiece has moved through a distance l.
So the fringe width be,

$$\beta = \frac{l}{20}$$

Now move the lens towards eyepiece and bring it to other position L_2

So that again images of A and B are seen clearly in the the field of view

Of eyepiece. Again if the distance between the two images be $\mathbf{d_2}$



$$\frac{d_2}{d} = \frac{v}{u} = \frac{m}{n} \qquad \text{........(2)}$$

Multiplying (1) and (2) we get

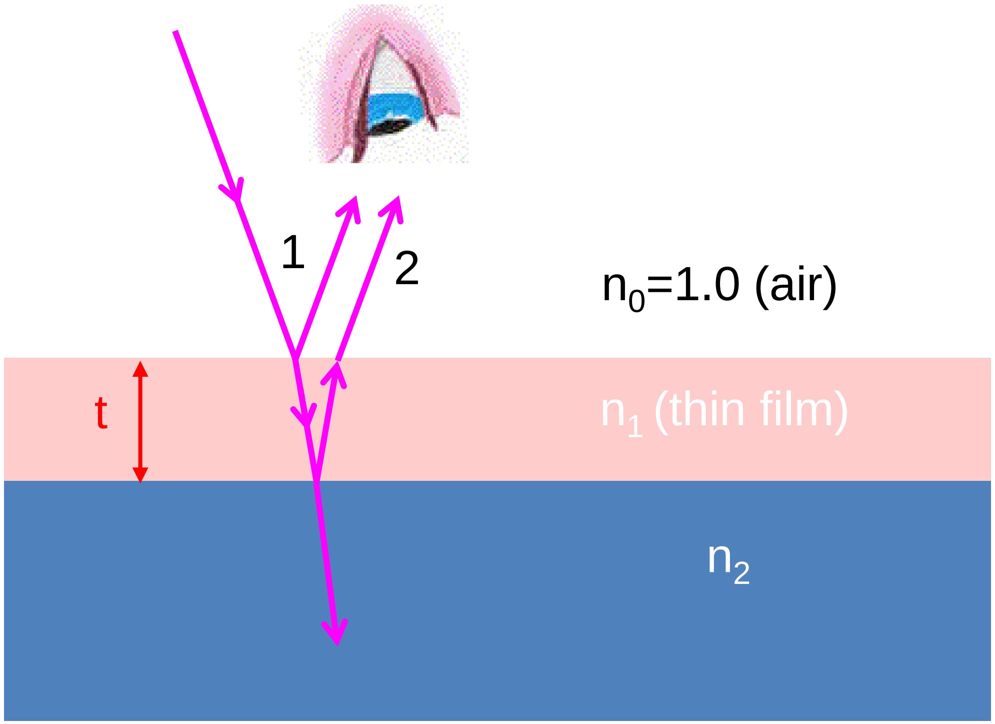
$$\frac{d_1 d_2}{d^2} = 1$$

$$\Rightarrow d = \sqrt{d_1 d_2}$$

Substituting the values of β, d, D we calculate the value of wavelength (λ) of given monochromatic light.

Thin Film Interference

Light is incident normal to a thin film

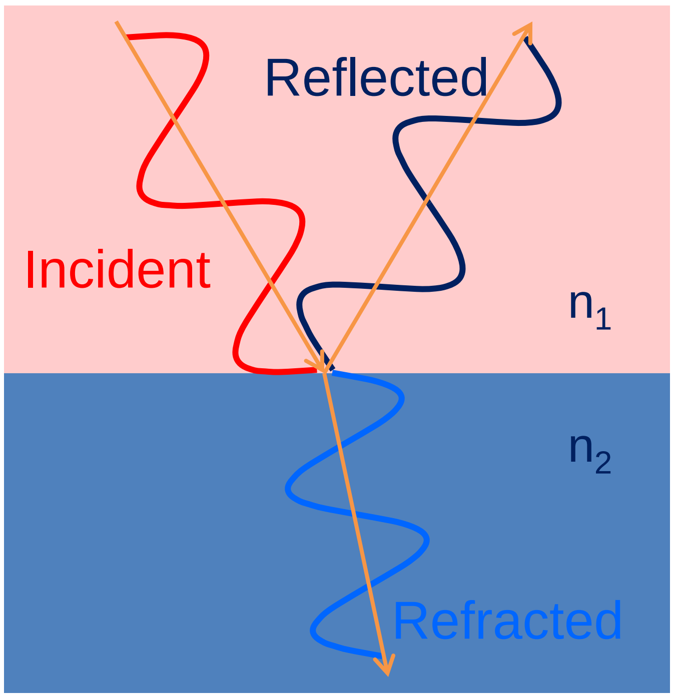


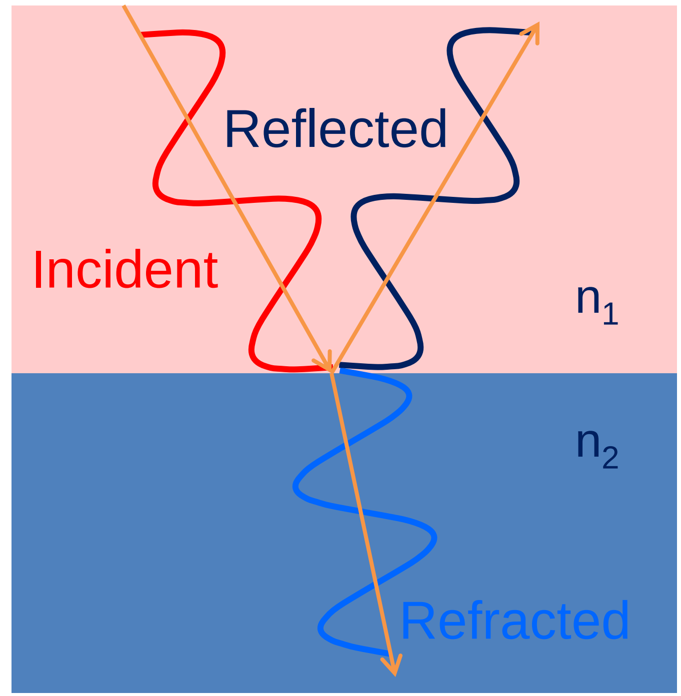
Get two waves by reflection off two different interfaces: interference!

Ray 2 travels approximately 2t further than ray 1.

Reflection & Phase Shifts

Upon reflection from a boundary between two transparent materials, the phase of the reflected light may change.



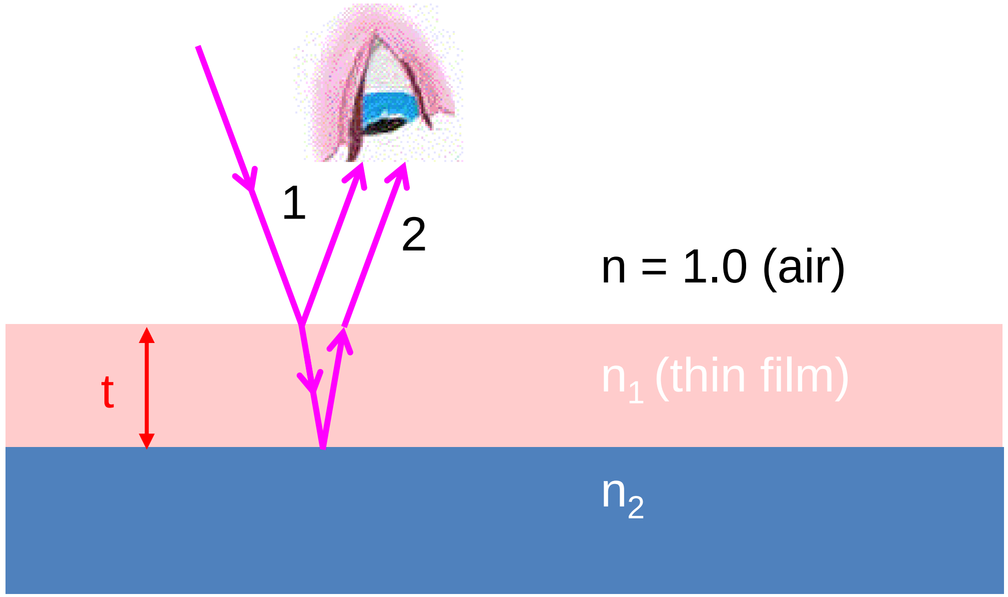


- If $n_1 > n_2$ – no phase change upon reflection

- If $n_1 < n_2$ – 180º phase change upon reflection (shift by $\lambda/2$)

Thin Film Summary

Determine δ, number of extra wavelengths for each ray.



This is important!

	Reflection		Distance
Ray 1:	δ_1 = 0 or ½	+	0
Ray 2:	δ_2 = 0 or ½	+	$2t/\lambda_{film}$

If $|\delta_2 - \delta_1|$ = 0, 1, 2, 3 …. (m) constructive

If $|\delta_2 - \delta_1|$ = ½ , 1 ½, 2 ½ …. (m + ½) destructive