Interference of Light Waves

Chapter 37

Interference

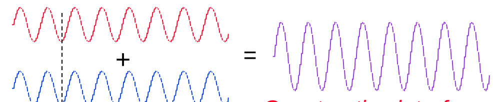
Young's Double Slit Experiment

Phasors

Intensity Distribution for Coherent Sources

Interference of waves

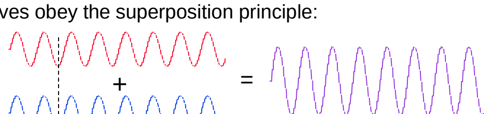
Waves obey the superposition principle:



- Constructive interference.

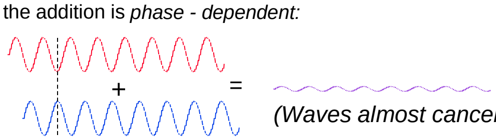
Interference of waves

Waves obey the superposition principle:



- Constructive interference.

But the addition is *phase - dependent:*



(Waves almost cancel.)

(Close to π out of phase)

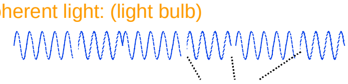
- Destructive interference.

Interference of waves

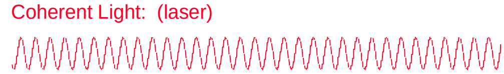
Coherence:

Most light will only have interference for small optical path differences (a few wavelengths), as the phase is not well defined over a long distance. Laser light is an exception:

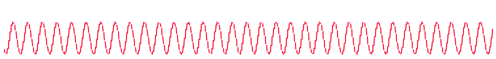
Incoherent light: (light bulb)



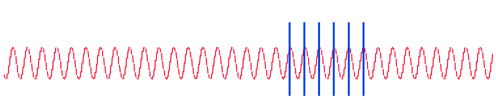
Coherent Light: (laser)



Wave Fronts



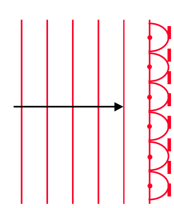
The peaks in the electric field amplitude are called wave fronts.



Wave fronts

Recall: Huygen's principle

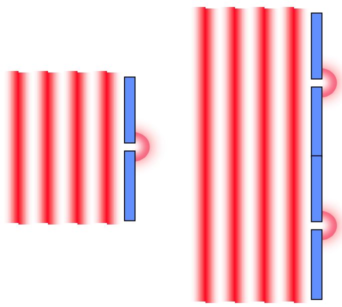
Huygen first explained this in 1678 by proposing that all planar wave fronts are made up of lots of spherical wave fronts.



That is, you see how light propagates by breaking a wave front into little bits, and then draw a spherical wave emanating outward from each little bit. You then can find the leading edge a little later simply by summing all these little "wavelets"

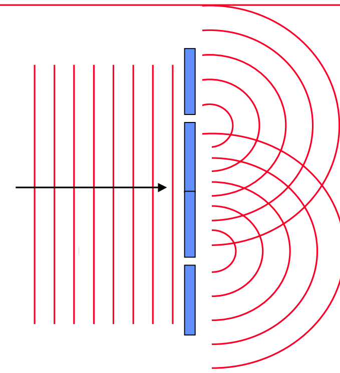
It is possible to explain reflection and refraction this way too.

Double-Slit Interference



these waves will eventually interfere with one another... produce "interference fringes'

Double-Slit Interference



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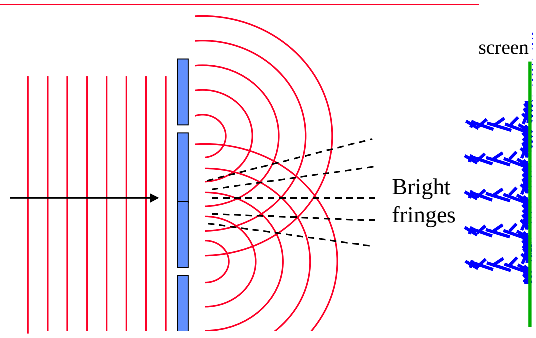
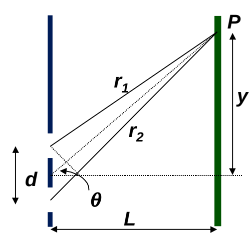


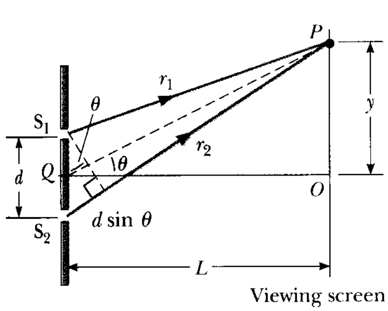
Thomas Young (1802) used double-slit interference to prove the wave nature of light.

Double-Slit Interference

Thomas Young (1802) experiment.
Proved the wave nature of light

Diffraction from two slits produce fringes





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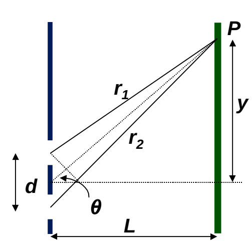


r_1 and r_2 have different path lengths. At the slits the two waves are in phase. When they reach P they are out of phase by the path difference $\delta = r_2 - r_1$.

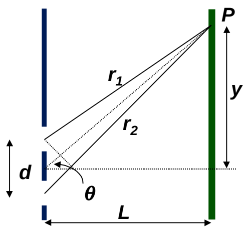
$\delta \cong d \sin\theta$

If $\delta = m\lambda$ constructive interference
and if $\delta = (m+1/2)\lambda$ destructive interference.

Double-Slit Interference

Thomas Young (1802) experiment.
Proved the wave nature of light

Diffraction from two slits produce ***fringes***



d* sin *θ* = *m λ **bright fringes**

d* sin *θ* = (*m*+1/2) *λ **dark fringes**

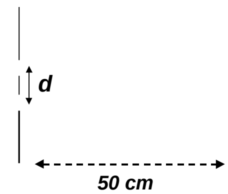
Position of fringes

$y_{bright} = m\lambda L/d$

$y_{dark} = (m+1/2)\lambda L/d$

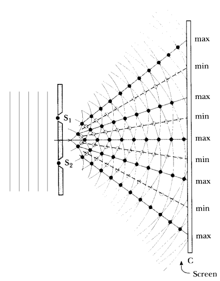
Example: Double slit interference

Light of wavelength λ = 500 nm is incident on a double slit spaced by d = 50 μm. What is the fringe spacing on the screen, 50 cm away?

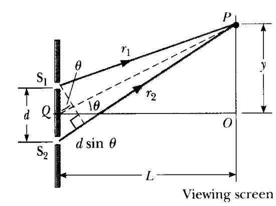


Example: Double slit interference

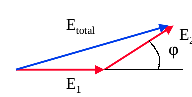
Two slits separated by 0.2 mm are illuminated with a laser of wavelength 421 nm. Estimate the distance from the central bright-region to the 2nd dark fringe if the screen is 1.8 m away.



Phasors



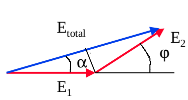
At point P, the electric field of S_1 will oscillate in time although the position is fixed at y.
Likewise S_2 will oscillate in time at position P, but with a phase shift due to its different pathlength, r_2 (= r_1 + dsin(θ)).
This difference in distance corresponds to an angular or phase difference between S_1 and S_2.
$\varphi = k(r_2 - r_1)$



$$\phi = kd \sin\theta = \frac{2\pi}{\lambda} d \sin\theta$$

$$\frac{\phi}{2\pi} = \frac{d\sin\theta}{\lambda} \cong \frac{dy}{\lambda L}$$

Phasors



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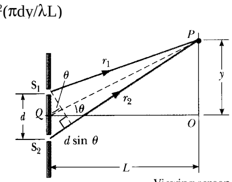
$$\frac{\phi}{2\pi} = \frac{d\sin\theta}{\lambda} \cong \frac{dy}{\lambda L}$$

$\alpha = \phi/2$, $|E_1| = |E_2| = E$

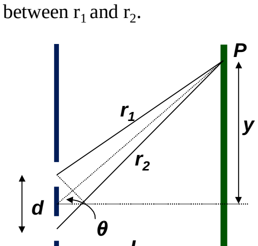
$E_{total} = 2E\cos(\alpha) = 2E\cos(\phi/2) = 2E\cos(\pi\, d\sin(\theta)/\lambda)$
$I \propto E_{total}^2 \rightarrow I = 4I_1\cos^2(\pi\, d\sin(\theta)/\lambda) \cong 4I_1\cos^2(\pi dy/\lambda L)$
where I_1 is the intensity at S_1 (or S_2, they are same).

$I = I_o\cos^2(\pi\, d\sin(\theta)/\lambda) \cong I_o\cos^2(\pi\, dy/\lambda L)$
Where I_o is the peak intensity at the screen



Example: Double slit interference

Two slits separated by 0.4 mm are illuminated with a laser of wavelength 500 nm. Estimate the distance from the central bright-region to the first point P where the Intensity drops to 1/2 of its maximum. Assume the screen is 2.0 m from the apertures. Also calculate the phase difference between r_1 and r_2.



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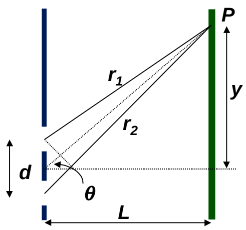

$I = I_o\cos^2(\pi\, d\sin(\theta)/\lambda) \cong I_o\cos^2(\pi\, dy/\lambda L)$

Where I_o is the peak intensity at the screen

$I_o/2 \cong I_o\cos^2(\pi\, dy/\lambda L)$,

$1/2 = \cos^2(\pi\, dy/\lambda L)$

solve for y

$$y = \cos^{-1}\left(\tfrac{1}{\sqrt{2}}\right)\frac{\lambda L}{\pi d} = \frac{\pi}{4}\frac{\lambda L}{\pi d}$$

$$y = 0.625 \text{ mm}$$

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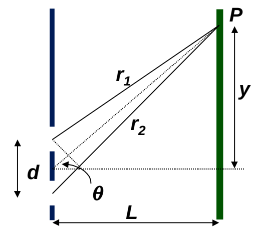

Phase difference between r_1 and r_2

$$\frac{\phi}{2\pi} \cong \frac{dy}{\lambda L} \Rightarrow \phi = 2\pi\frac{dy}{\lambda L}$$

$$\phi = \frac{\pi}{2}$$