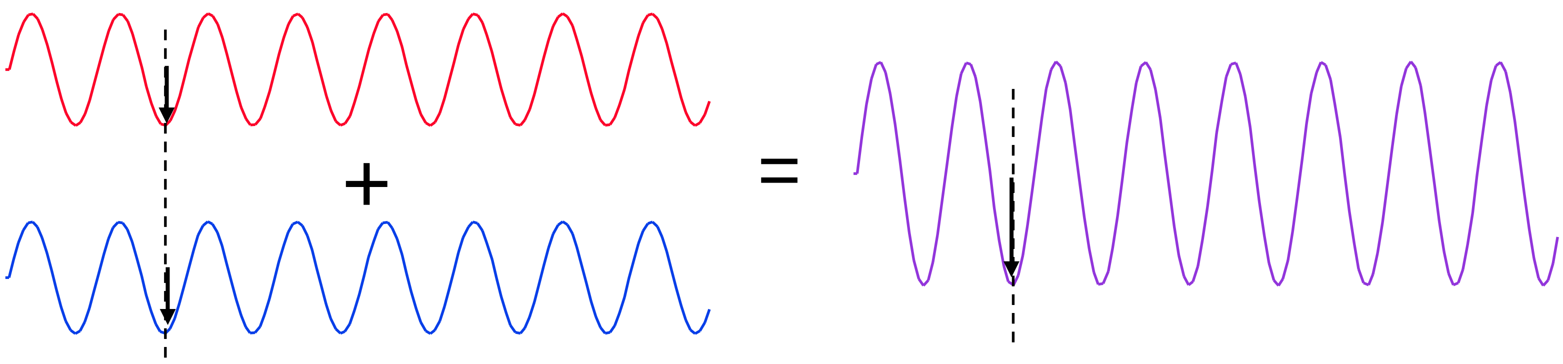
Combination of Waves

In general, when we combine two waves to form a composite wave, the composite wave is the algebraic sum of the two original waves, point by point in space [Superposition Principle].

When we add the two waves we need to take into account their:

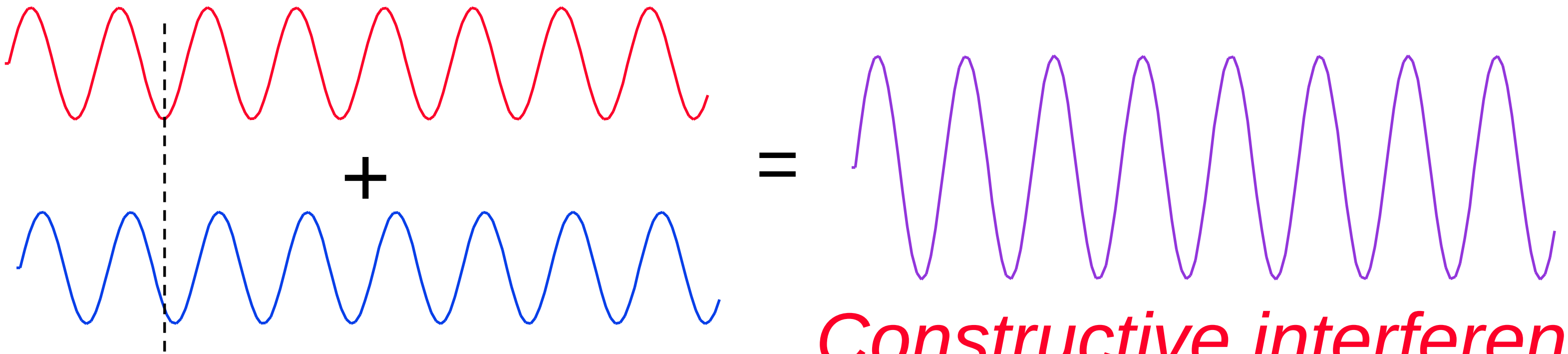
- **Direction**
- **Amplitude**
- **Phase**



Combination of Waves

The combining of two waves to form a composite wave is called:

Interference



(Waves almost in phase)

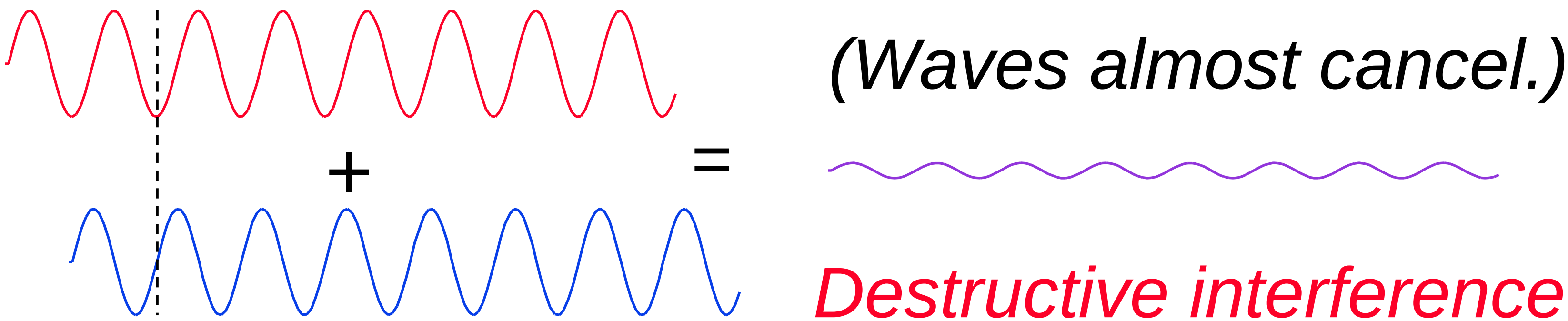
Constructive interference

The interference is constructive
if the waves reinforce each other.

Combination of Waves

The combining of two waves to form a composite wave is called:

Interference

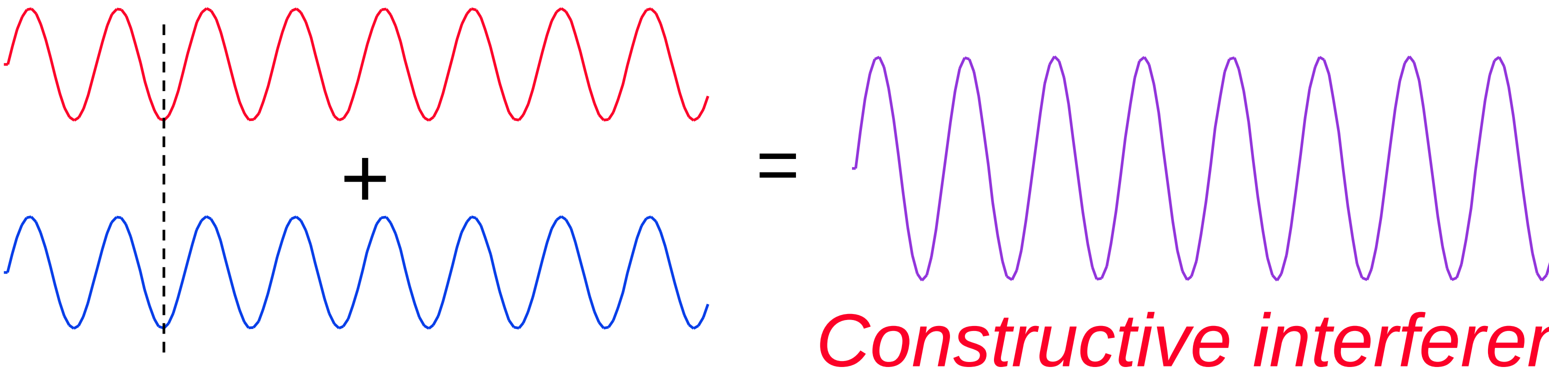


Destructive interference

(Close to π out of phase)

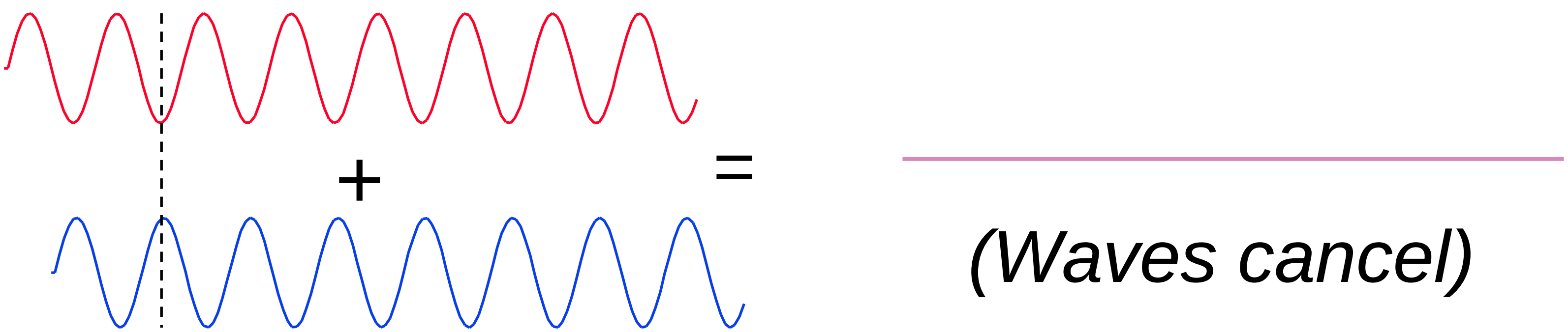
The interference is destructive
if the waves tend to cancel each other.

Interference of Waves



(In phase)

Constructive interference



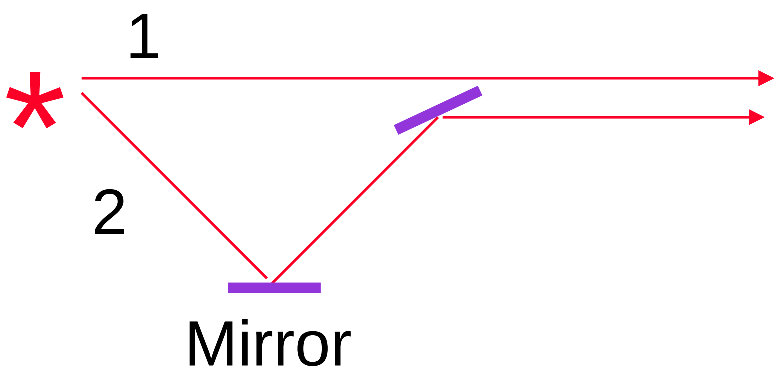
(Waves cancel)

(π out of phase)

Destructive interference

Interference of Waves

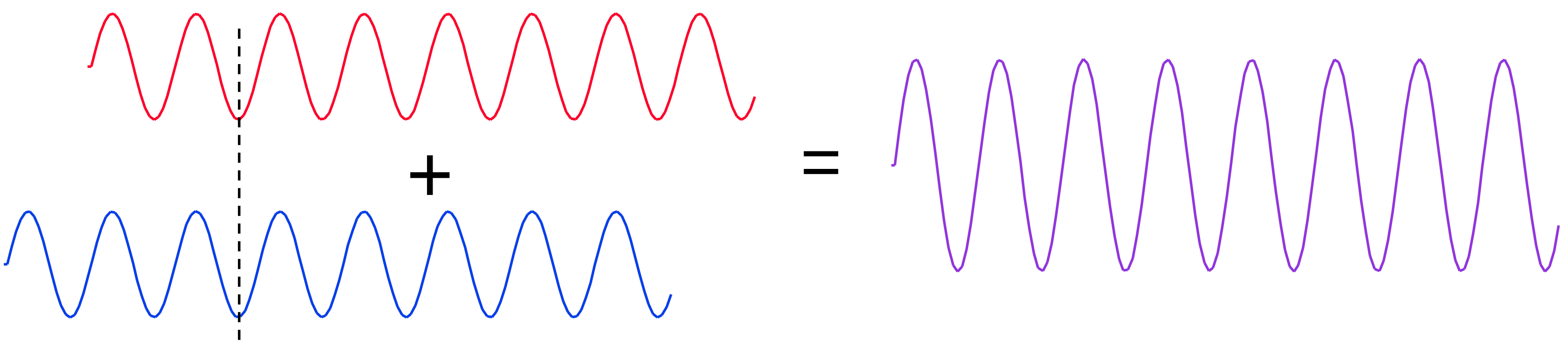
When light waves travel different paths, and are then recombined, they *interfere.*



Each wave has an electric field whose amplitude goes like:

$$\underline{\mathbf{E}}(s,t) = E_0 \sin(ks-\omega t)\ \hat{\imath}$$

Here s measures the distance traveled along each wave's path.



Constructive interference results when light paths differ by an integer multiple of the wavelength: $\Delta s = m\,\lambda$

Interference of Waves

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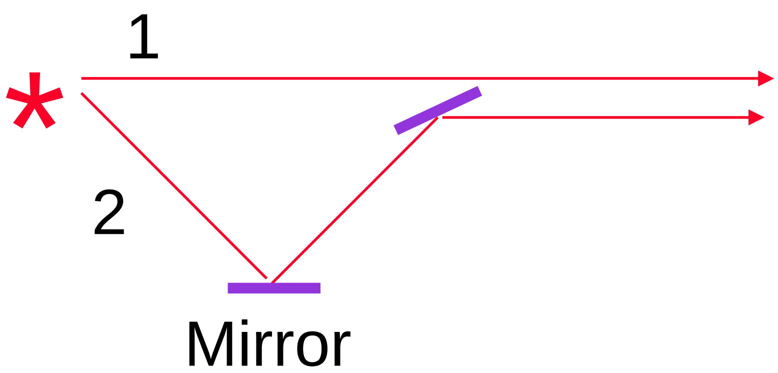

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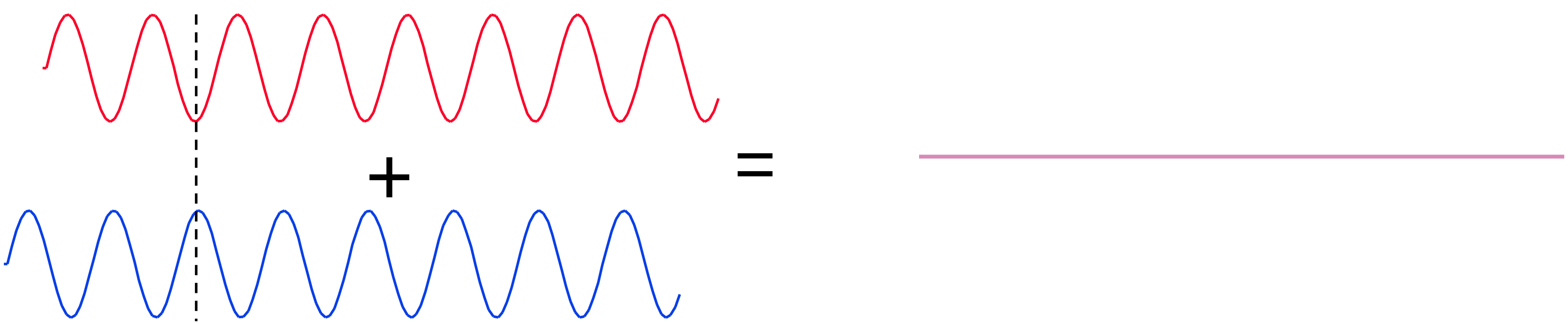
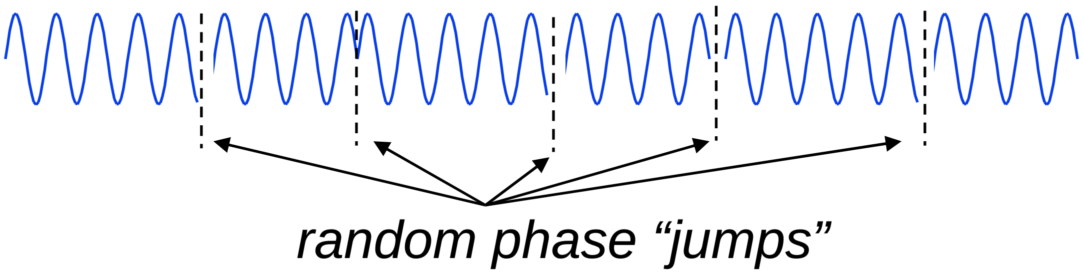


Destructive interference results when light paths differ by an odd multiple of a half wavelength: $\Delta s = (2m+1)\,\lambda/2$

Interference of Waves

Coherence: Most light will only have interference for small optical path differences (a few wavelengths), because the phase is not well defined over a long distance. That's because most light comes in many short bursts strung together.

Incoherent light: (light bulb)



Interference of Waves

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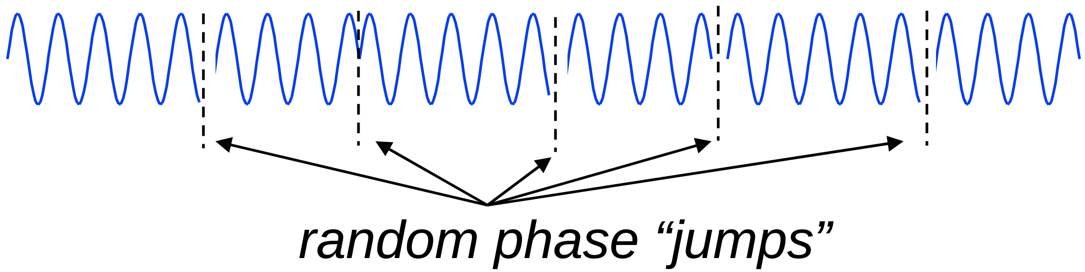
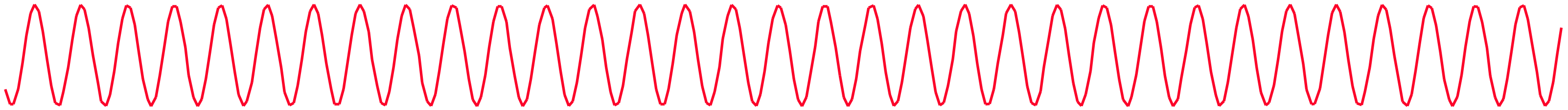
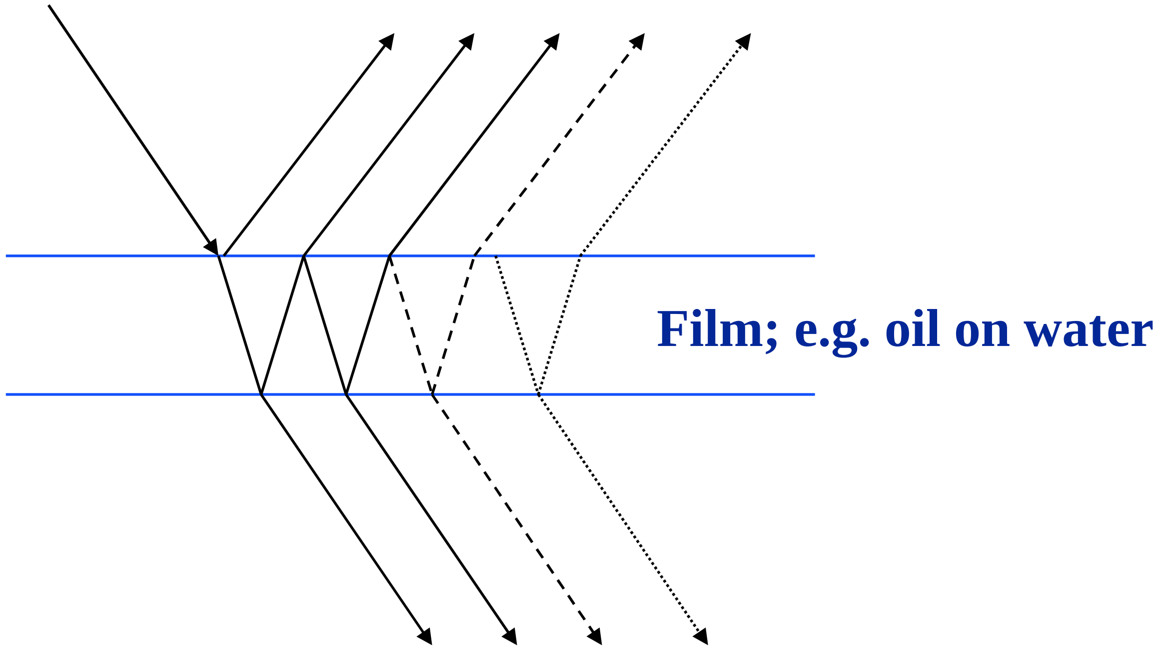


Laser light is an exception: Coherent Light: (laser)



Thin Film Interference

We have all seen the effect of colored reflections from thin oil films, or from soap bubbles.



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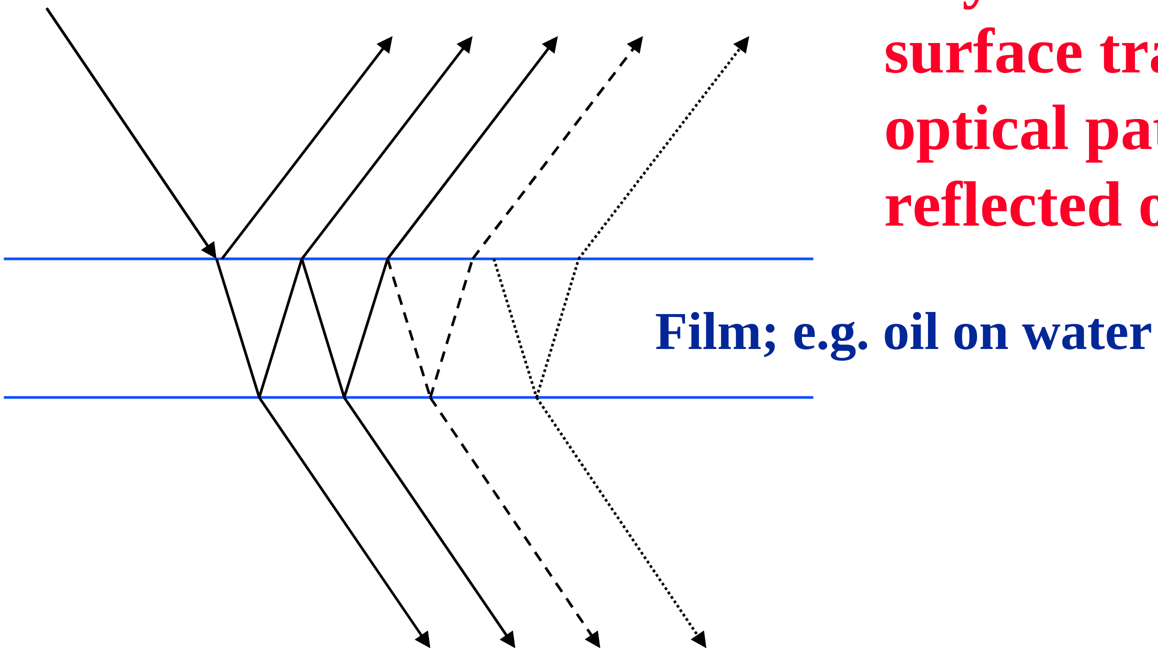

Rays reflected off the lower surface travel a longer optical path than rays reflected off upper surface.

Thin Film Interference

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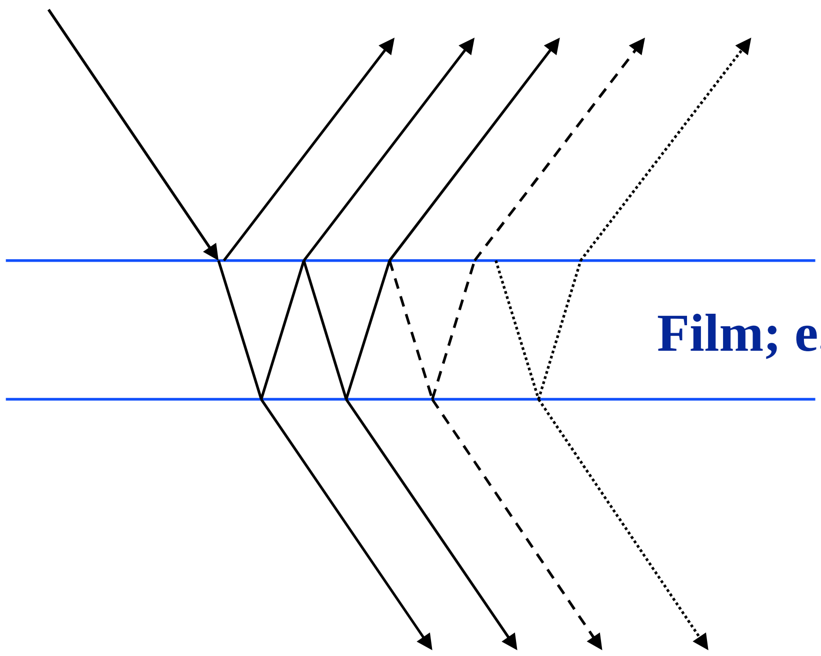


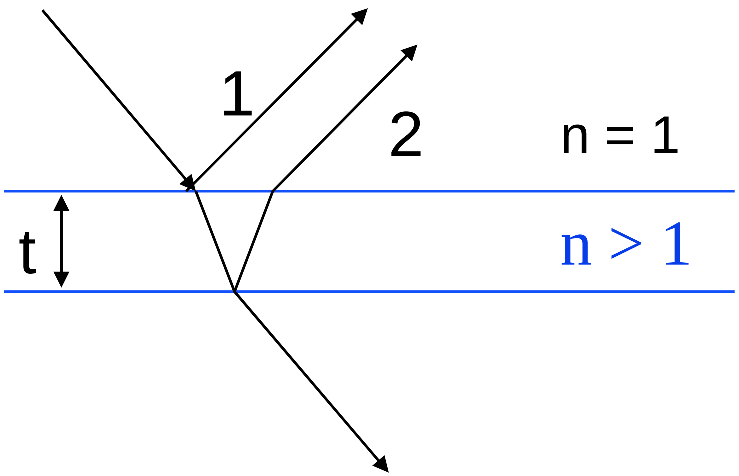
Rays reflected off the lower surface travel a longer optical path than rays reflected off upper surface.

Film; e.g. oil on water

If the optical paths differ by a multiple of λ, the reflected waves add.
If the paths cause a phase difference π, reflected waves cancel out.

Thin Film Interference

Ray 1 has a phase change of π upon reflection
Ray 2 travels an extra distance 2t (normal incidence approximation)



oil on water
optical film on glass
soap bubble

Constructive interference: rays 1 and 2 are in phase

$\Rightarrow 2\,t = m\,\lambda_n + ½\,\lambda_n \Rightarrow \boxed{2\,n\,t = (m + ½)\,\lambda}$ $[\lambda_n = \lambda/n]$

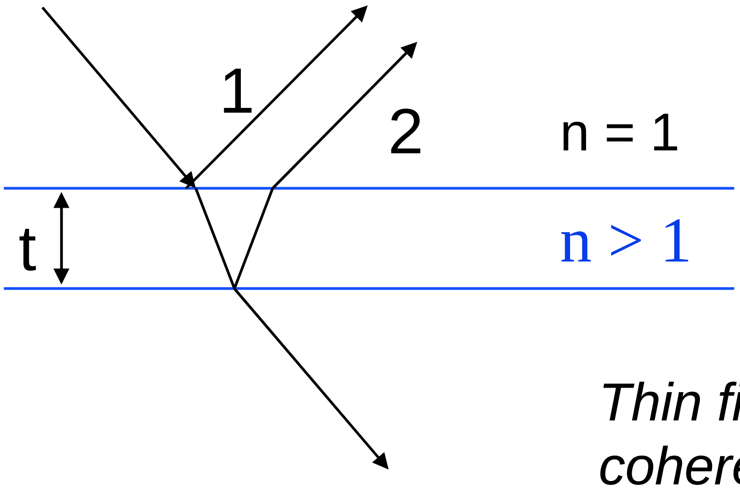
Destructive interference: rays 1 and 2 are π out of phase

$\Rightarrow 2\,t = m\,\lambda_n \Rightarrow \boxed{2\,n\,t = m\,\lambda}$

Thin Film Interference

When ray 2 is in phase with ray 1, they add up constructively and we see a bright region.

Different wavelengths will tend to add constructively at different angles, and we see bands of different colors.



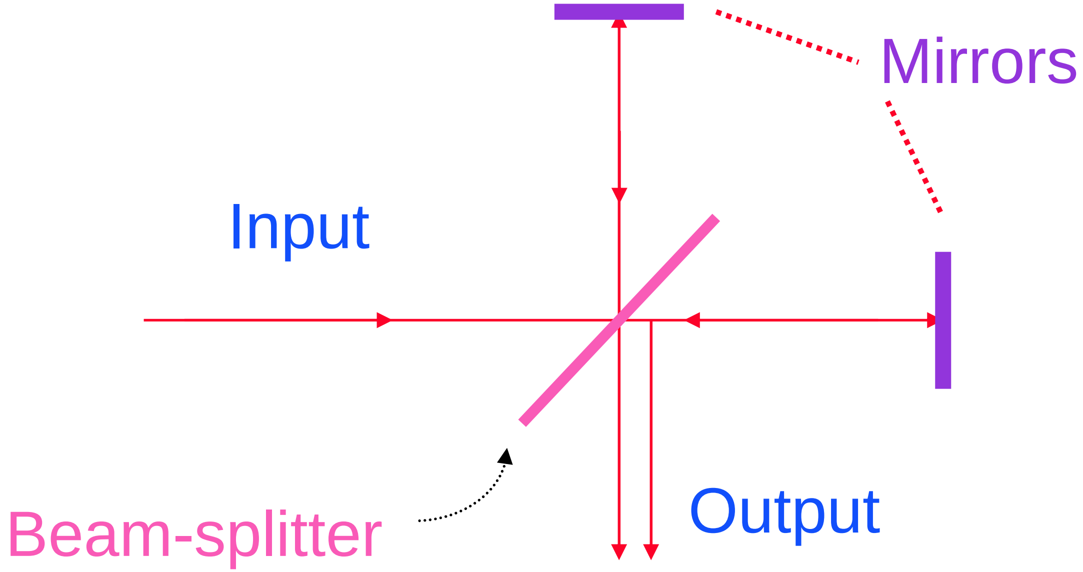
oil on water
optical film on glass
soap bubble

Thin films work with even low coherence light, as paths are short

When ray 2 is π out of phase, the rays interfere destructively. This is how anti-reflection coatings work.

Michelson Interferometer

A Michelson interferometer uses a beam splitter to create two different optical paths.

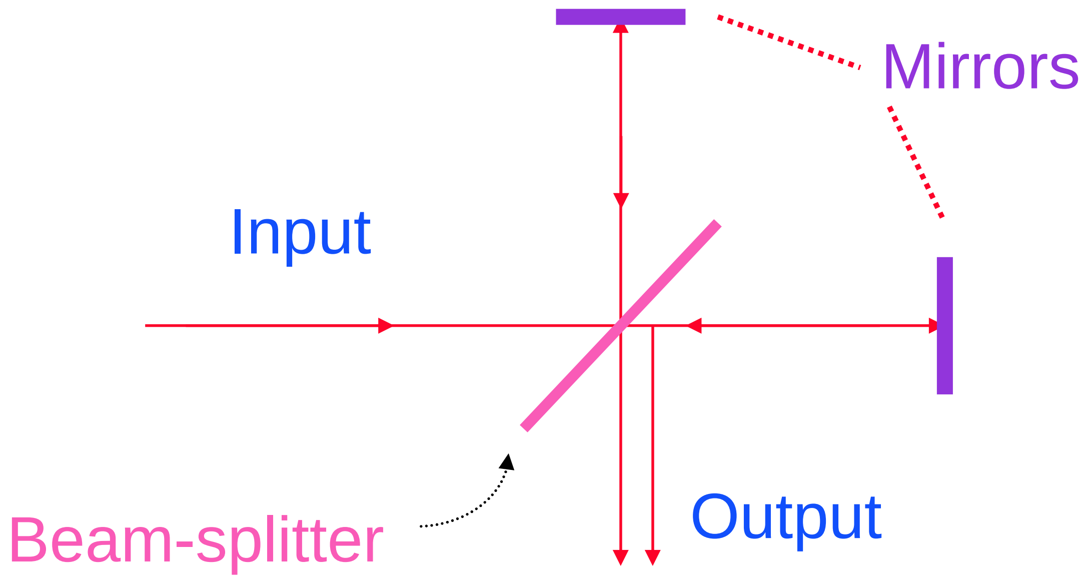


What is the output?

- If the output beams are perfectly aligned, they will interfere uniformly, giving either a bright or dark output, depending on their relative phase.

Michelson Interferometer

A Michelson interferometer uses a beam splitter to create two different optical paths L_1 and L_2



$\Delta L = L_1 – L_2 = m\lambda \Rightarrow$ constructive interference, bright spot

$\Delta L = L_1 – L_2 = (m+1/2)\lambda \Rightarrow$ destructive interference, dark spot