

# Interference

Ken Intriligator's week 9 lecture, Nov.28, 2013



# Same as with sound

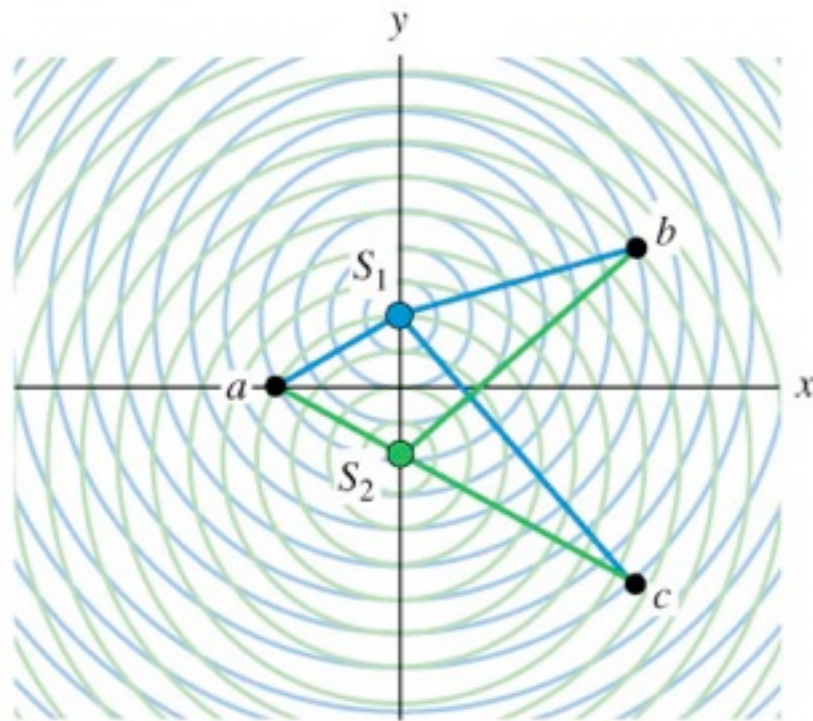
Superposition with light: Maxwell's equations are **linear** equations for  $E$  and  $B$ , so we can simply add the  $E$  and  $B$  of different sources to get the total  $E$  and  $B$ . Do this for light sources. **Intensity** is proportional to  **$E$ -squared**. Depending on the location, sources can either add or subtract: i.e. constructive or destructive interference.

**Constructive:  $E$ 's peaks from two sources aligned.**

**Destructive:  $E$ 's peaks from two sources anti-align.**

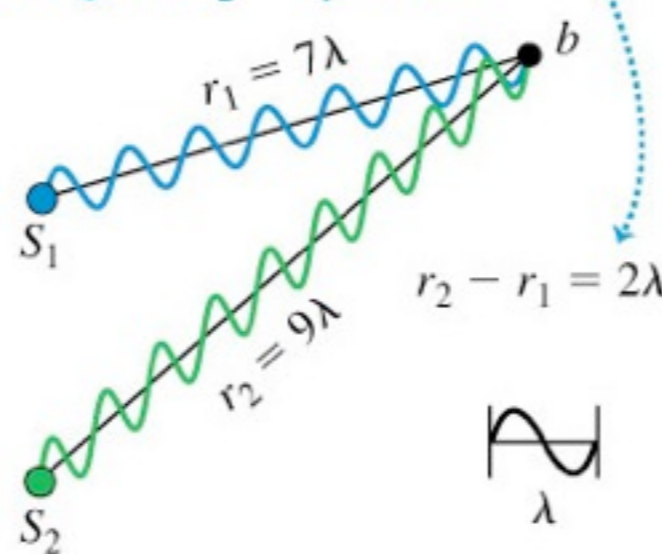
# Example:

(a) Two coherent wave sources separated by a distance  $4\lambda$



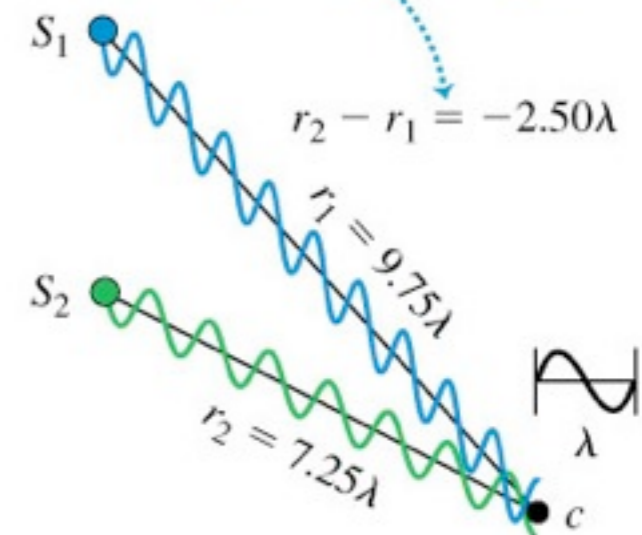
© 2012 Pearson Education, Inc.

(b) Conditions for constructive interference: Waves interfere constructively if their path lengths differ by an integral number of wavelengths:  $r_2 - r_1 = m\lambda$ .



© 2012 Pearson Education, Inc.

(c) Conditions for destructive interference: Waves interfere destructively if their path lengths differ by a half-integral number of wavelengths:  $r_2 - r_1 = (m + \frac{1}{2})\lambda$ .



© 2012 Pearson Education, Inc.

**Constructive:**

$$\Delta L = m\lambda$$

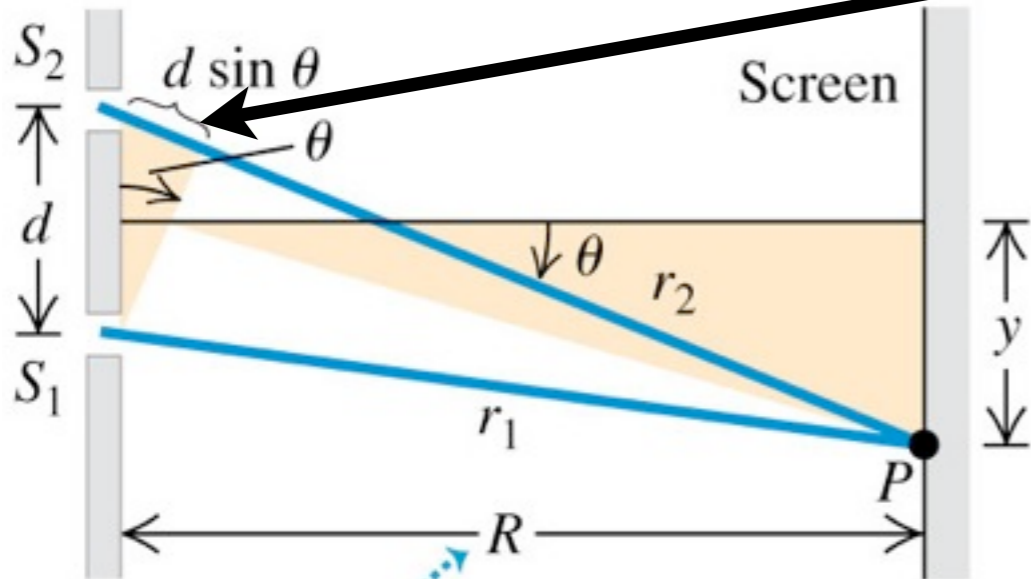
$$m = 0, \pm 1, \pm 2, \dots$$

**Destructive:**

$$\Delta L = (m + \frac{1}{2})\lambda$$

# Two source geometry

(b) Actual geometry (seen from the side)



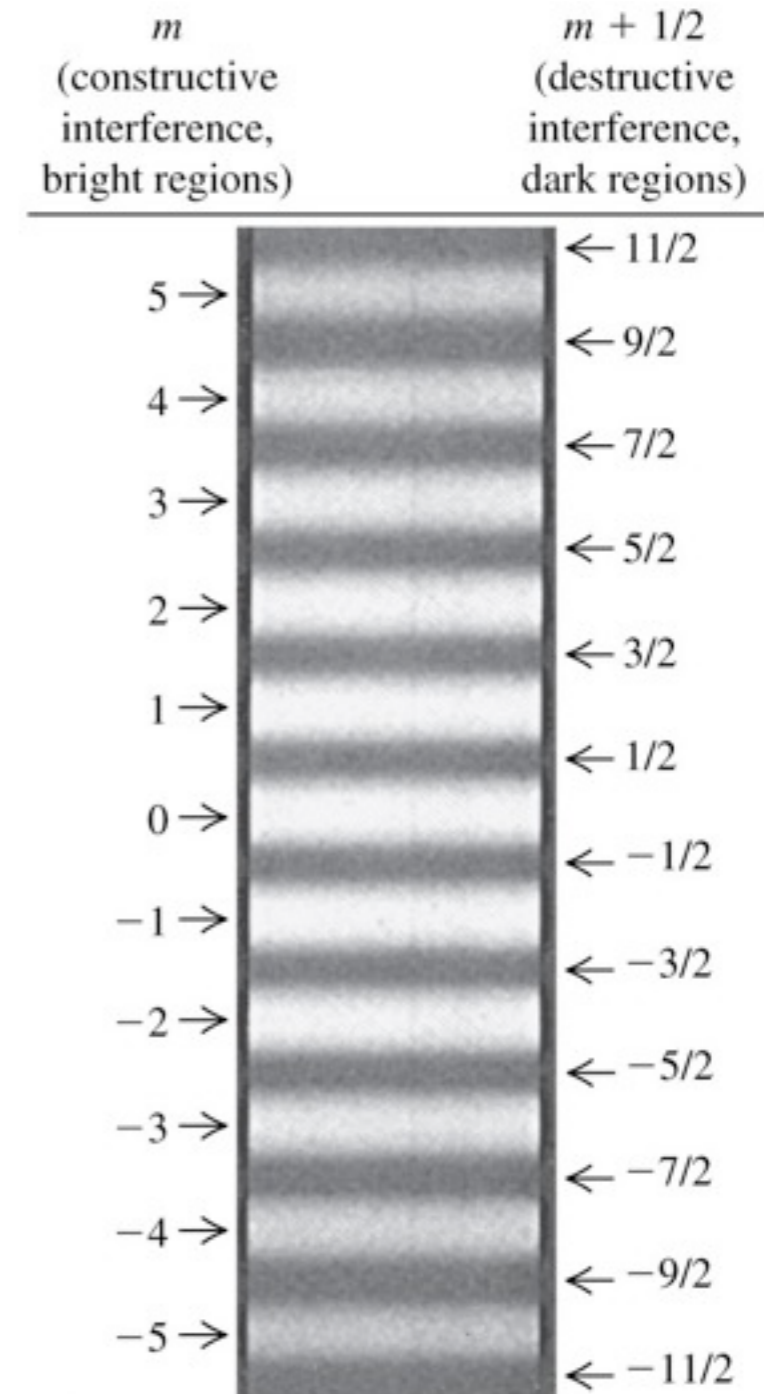
$$\Delta L \approx d \sin \theta$$

In real situations, the distance  $R$  to the screen is usually very much greater than the distance  $d$  between the slits ...

© 2012 Pearson Education, Inc.

**Bright:**  $d \sin \theta = m\lambda$

**Dark:**  $d \sin \theta = (m + \frac{1}{2})\lambda$



© 2012 Pearson Education, Inc.

# 2 sources intensity

(coherent)

$$I \sim \langle E_{tot}^2 \rangle \quad \text{(Time averaged)}$$

Recall trig identity:

$$\cos a + \cos b = 2 \cos\left(\frac{a+b}{2}\right) \cos\left(\frac{a-b}{2}\right)$$

source 1 wave

source 2 wave

$$E_{tot}/E_0 = \cos(kL - \omega t) + \cos(kL' - \omega t) = 2 \cos\left(\frac{k\Delta L}{2}\right) \cos(kL_{ave} - \omega t)$$

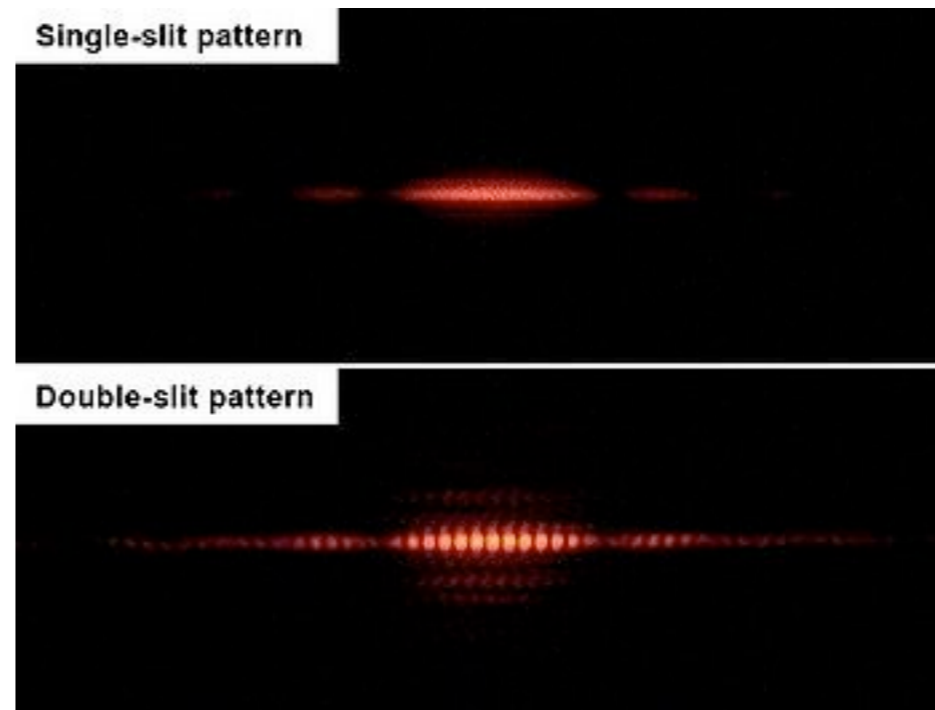
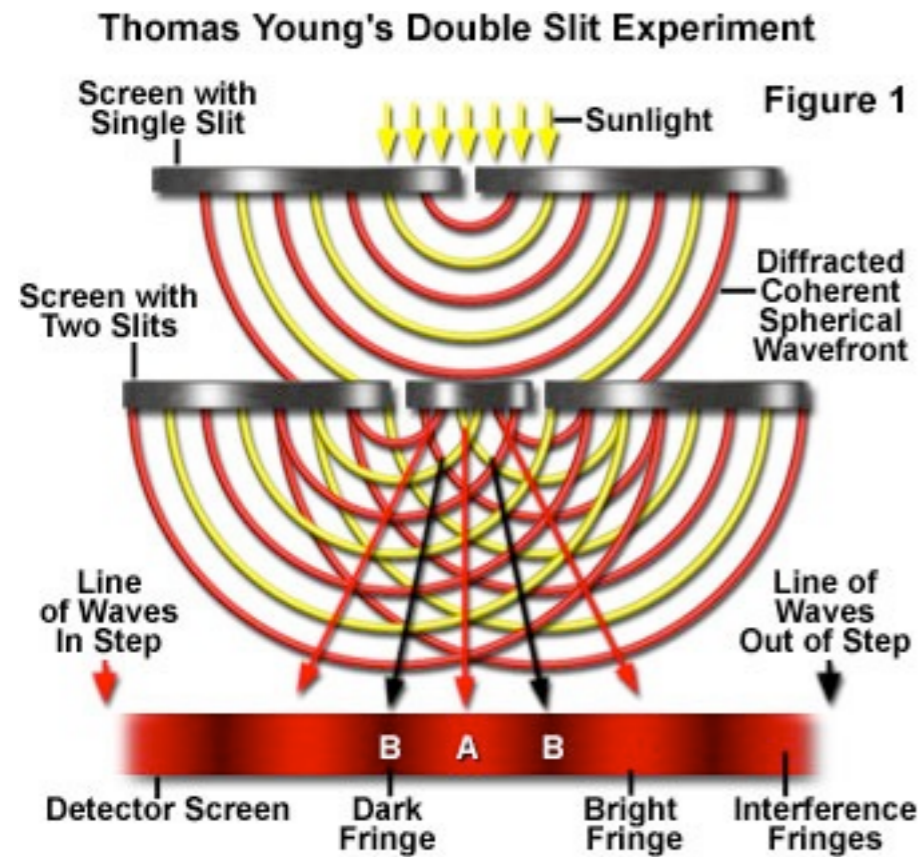
$$I_2 = 4I_1 \cos^2\left(\frac{1}{2}k\Delta L\right) = 4I_1 \cos^2(\pi\Delta L/\lambda)$$

interference amplitude, square it for intensity.

Constructive intensity peaks from 2 sources is 4 times that of a single source. Averaging over space gives

$$\overline{I_2} = 2I_1 \quad \text{since} \quad \overline{\cos^2 \theta} = \frac{1}{2} \quad \text{Makes sense.}$$

# Young expt. (1801)

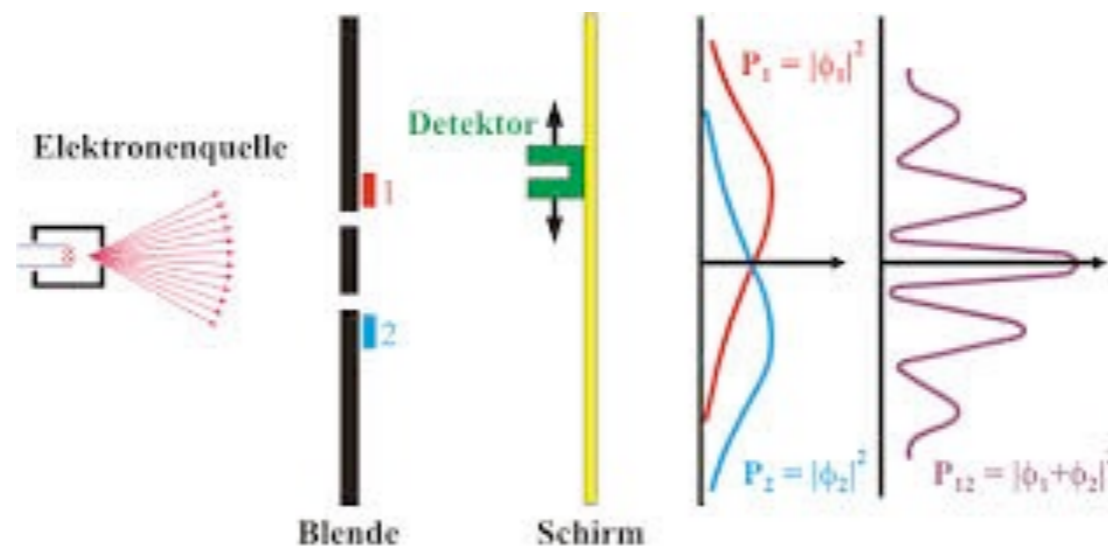
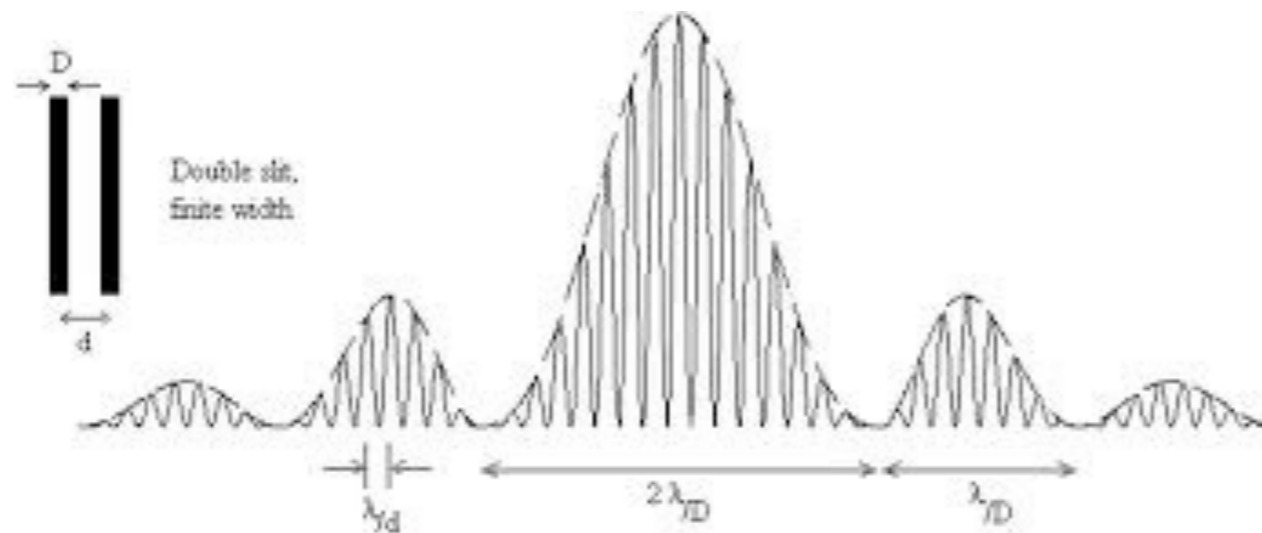


$$I_2 = 4I_1 \cos^2\left(\frac{1}{2}k\Delta L\right) = 4I_1 \cos^2(\pi\Delta L/\lambda)$$
$$\Delta L = d \sin \theta$$

$$I(\theta) \propto \cos^2(\pi d \sin \theta / \lambda) \quad \text{Shows light is a wave!}$$

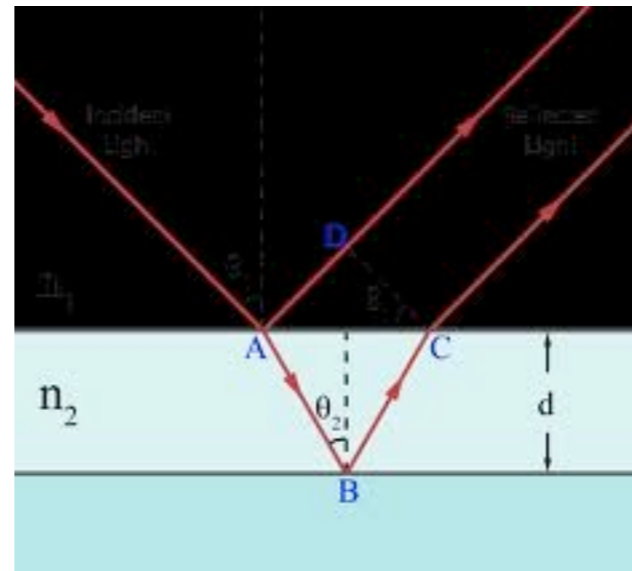
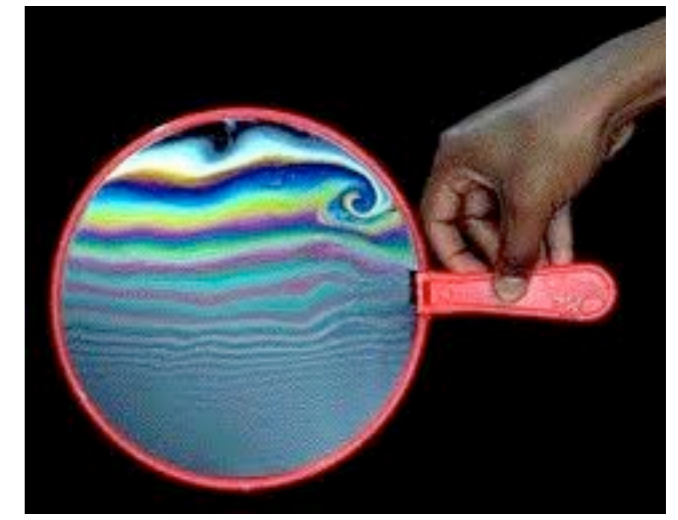
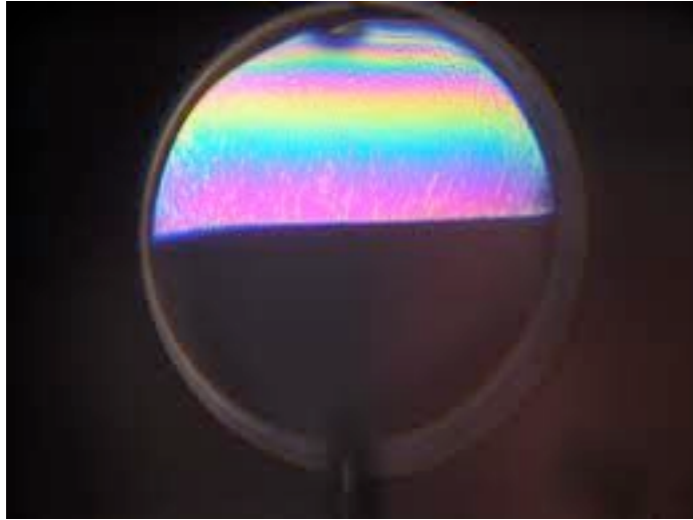
Actually small particles (e.g. electrons) behave same way (QM)!

# Double slit intensity



Actually small particles (e.g. electrons) behave same way (QM)!

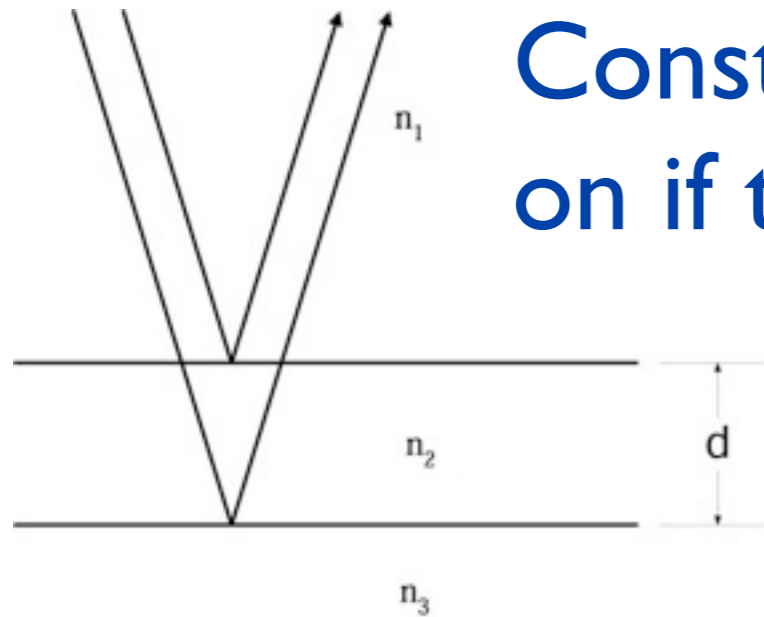
# thin films



even some critters!



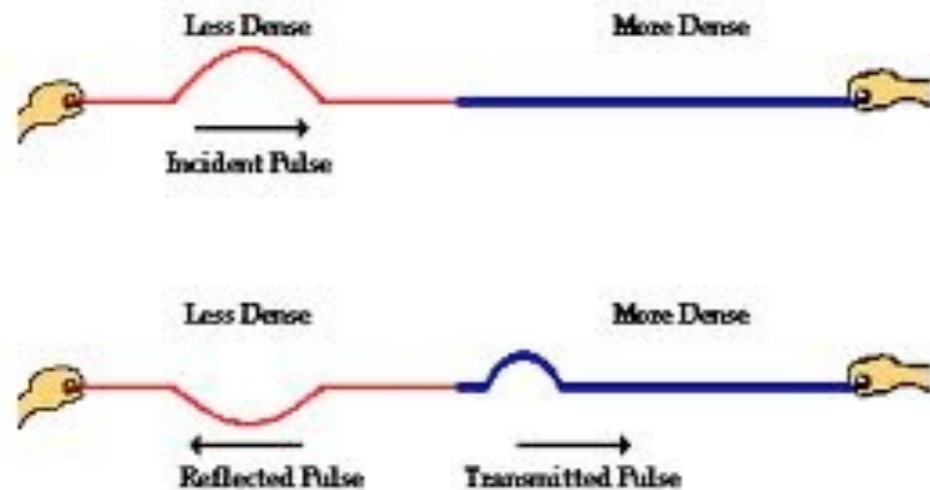
# thin film interference



Constructive / destructive depending on if two waves are in / out of phase.

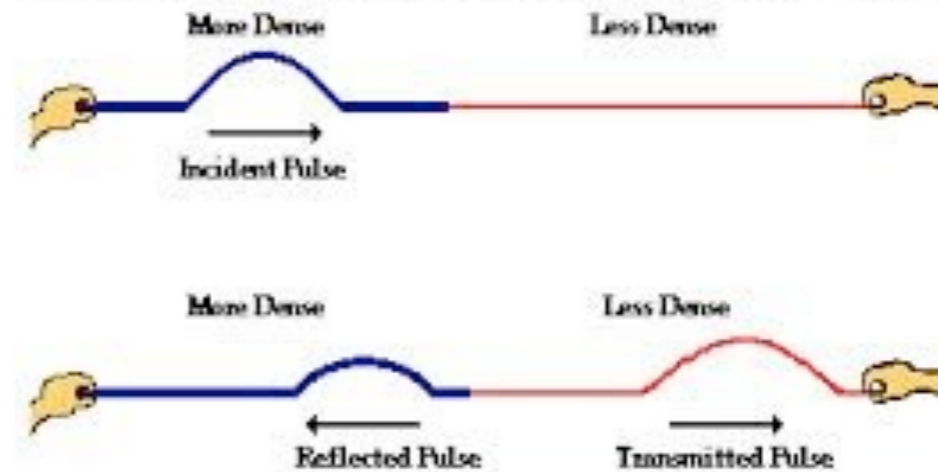
**RPS:** Reflected wave gets upside-down phase shifted if it hits bigger index  $n$ .

A wave traveling from a less dense to a more dense medium ...



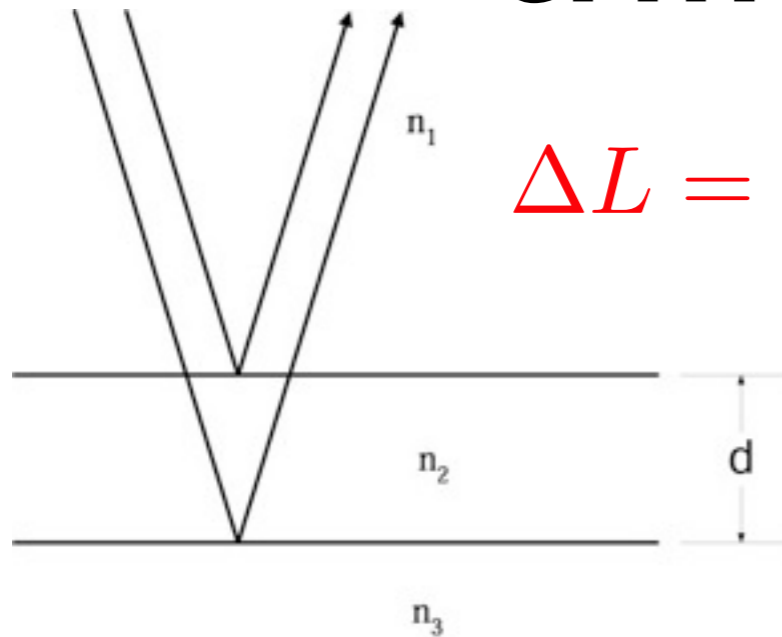
...will be reflected off the boundary and transmitted across the boundary into the new medium. The reflected pulse is inverted.

A wave traveling from a more dense to a less dense medium ...



...will be reflected off the boundary and transmitted across the boundary into the new medium. There is no inversion.

# thin films, cont.



$\Delta L = 2d$  Length difference of two rays.

$\lambda_{n_2} = \lambda_{vac}/n_2$  in material 2

$m = \text{integer}$ .

$$\Delta L = m\lambda_{n_2}$$

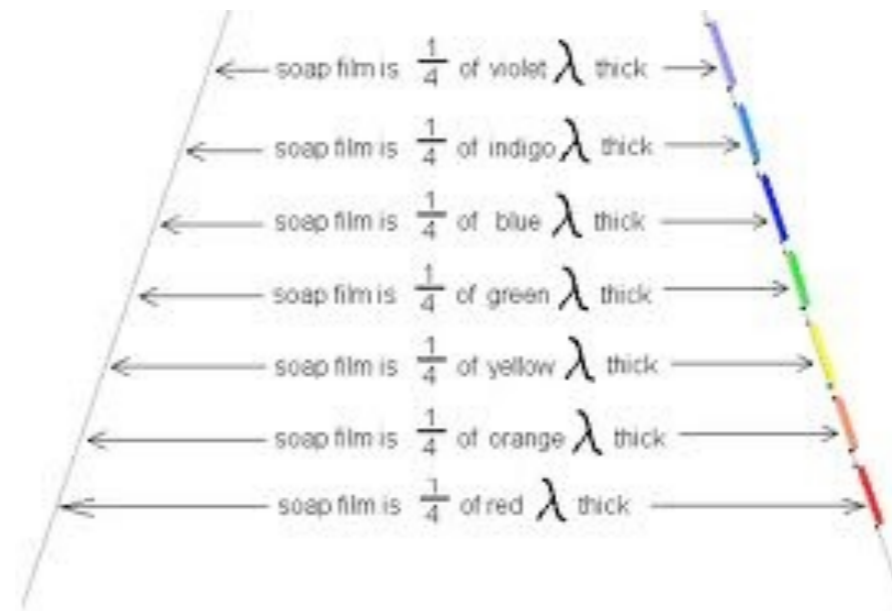
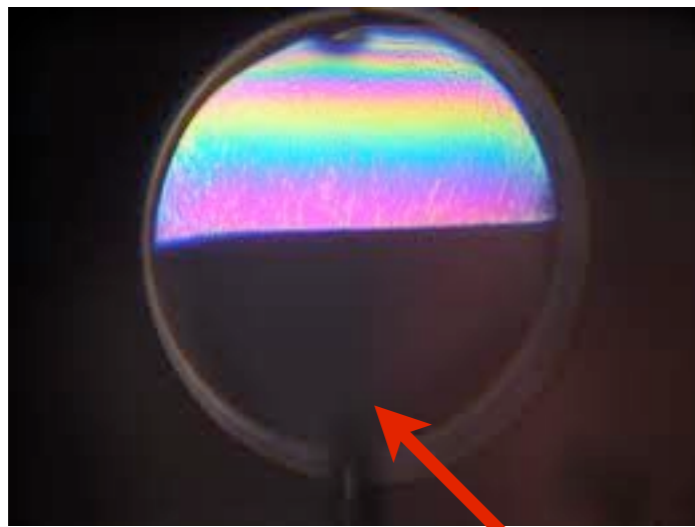
Constructive interference if 0 or 2 RPS's,  
**or** destructive interference if 1 RPS.

$$\Delta L = \left(m + \frac{1}{2}\right)\lambda_{n_2}$$

Destructive interference if 0 or 2 RPS's,  
**or** constructive interference if 1 RPS.

# e.g. soap bubble

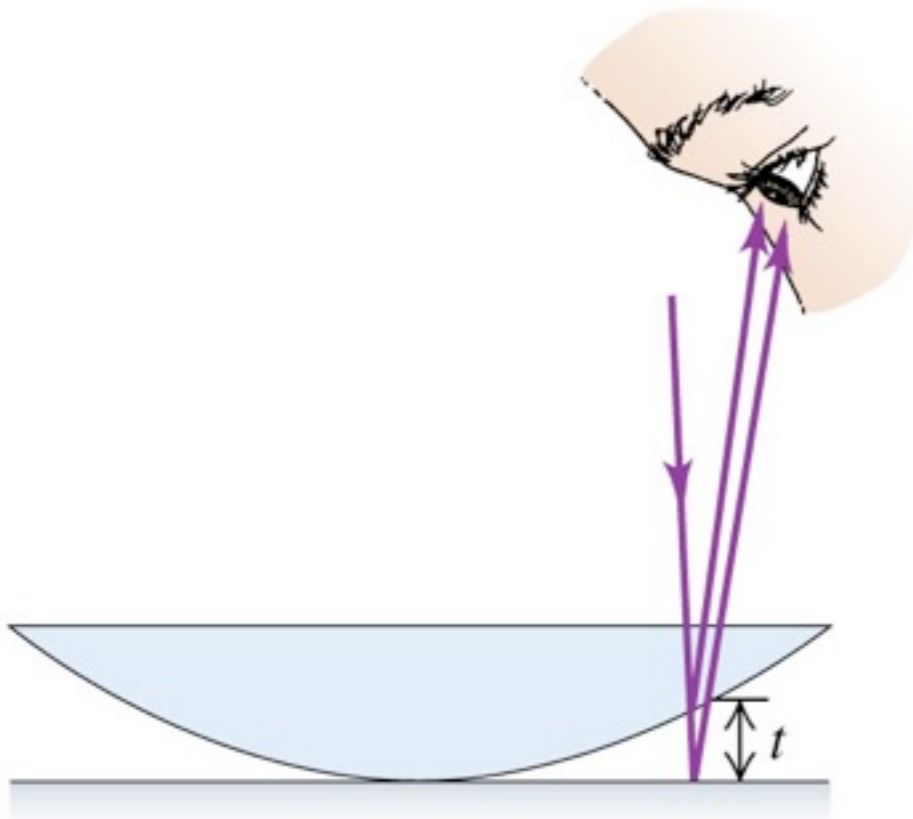
RPS from outer surface, not from inner surface.



(Constructive interference outside of visible range here.)

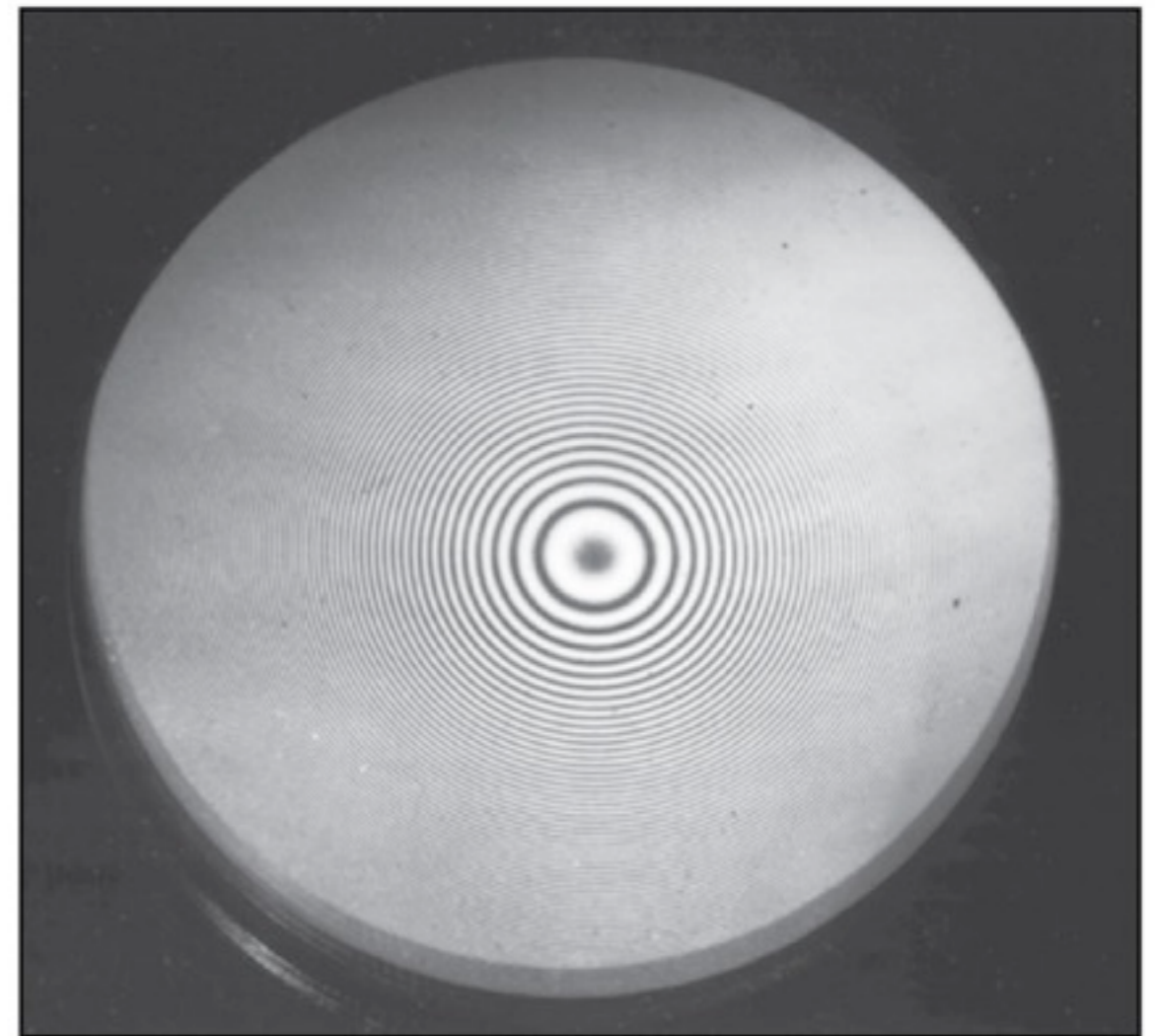
# Newton's rings

(a) A convex lens in contact with a glass plane



© 2012 Pearson Education, Inc.

(b) Newton's rings: circular interference fringes



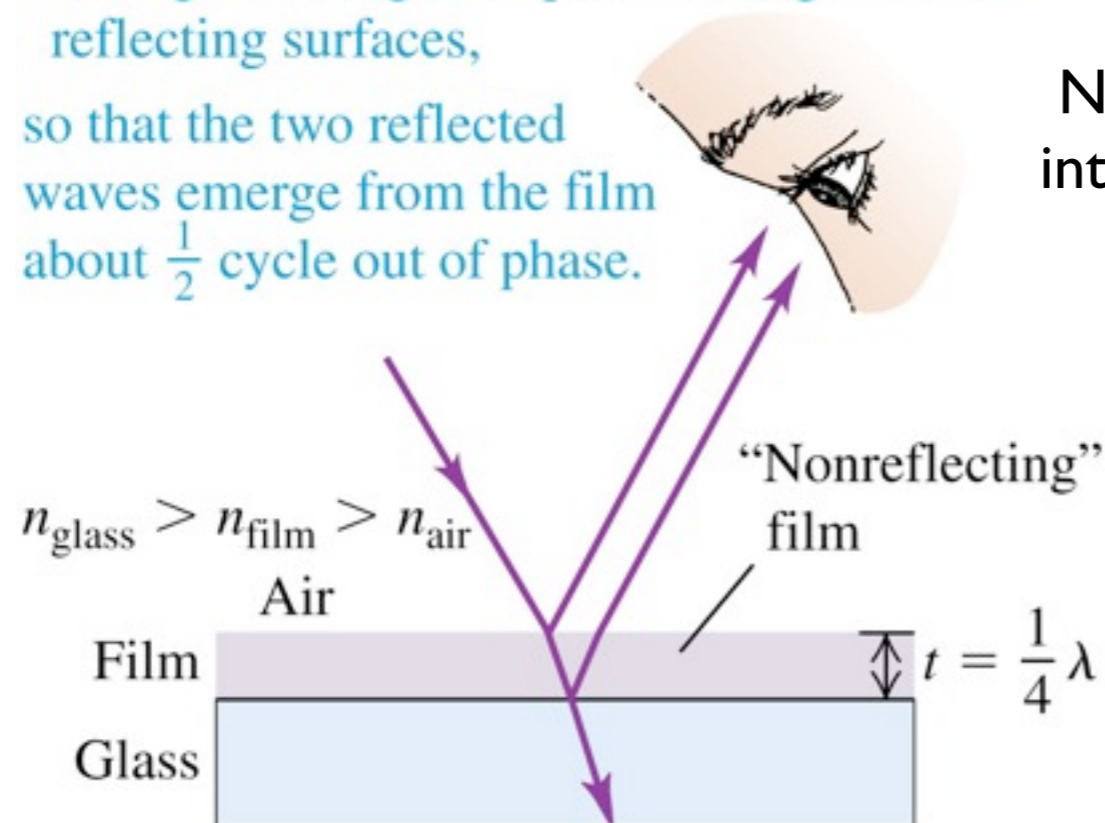
© 2012 Pearson Education, Inc.

# nonreflective coatings

Destructive interference occurs when

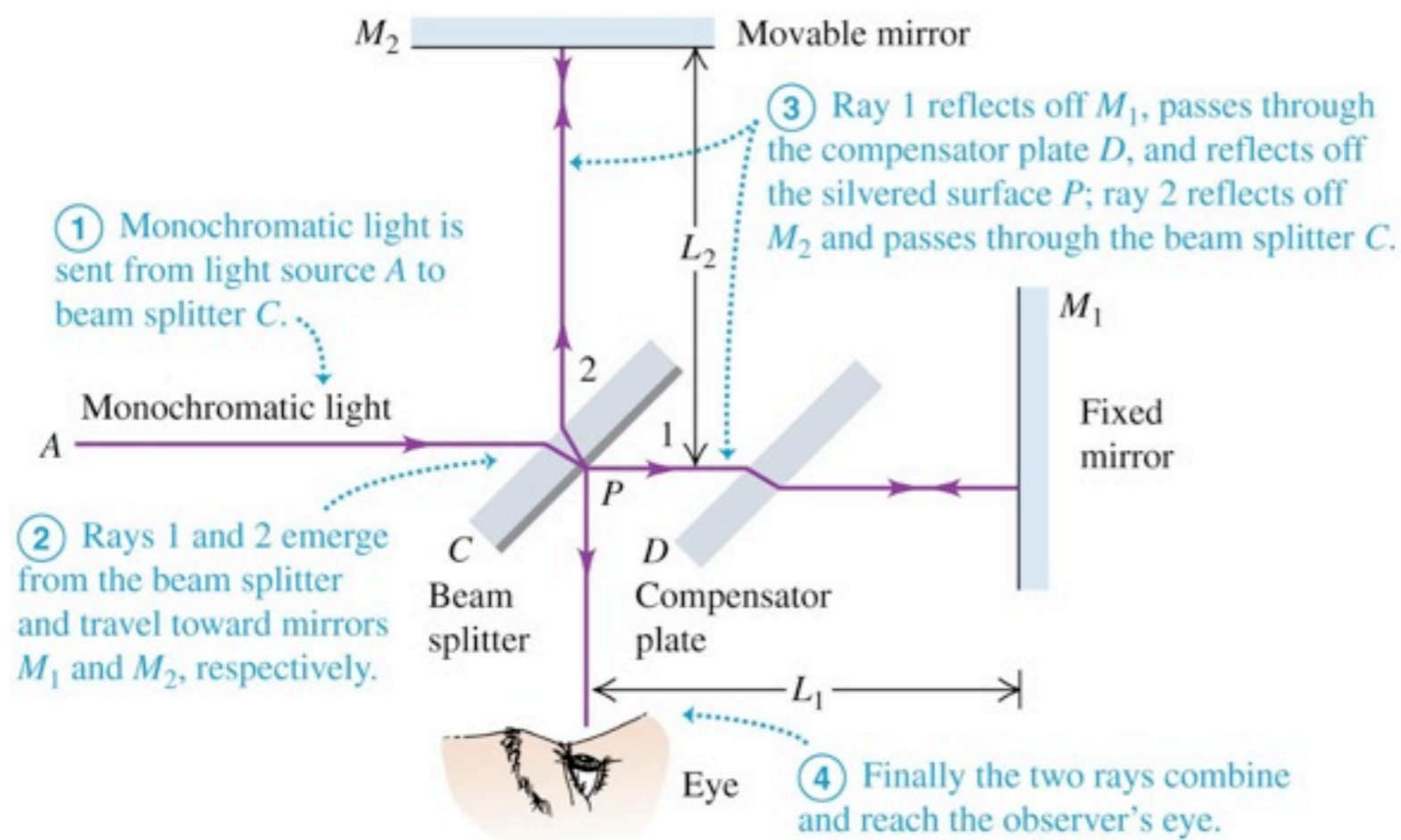
- the film is about  $\frac{1}{4}\lambda$  thick and
- the light undergoes a phase change at both reflecting surfaces,

so that the two reflected waves emerge from the film about  $\frac{1}{2}$  cycle out of phase.

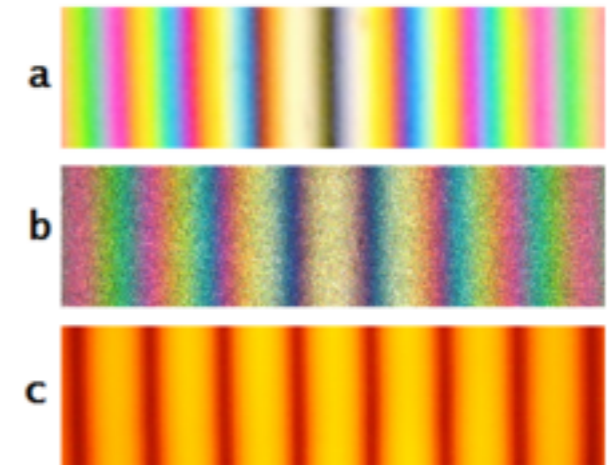


Note both reflections give a RPS, so destructive interference when the length difference is an odd number of half wavelengths.

# Michelson interferometer



Two paths interfere, based on their length difference. If the lengths are changed, find interference fringes move. Can measure lengths, and wavelengths very accurately this way.



# E.g. LIGO



Huge laser interferometer, looking for tiny length changes from gravitational waves. Hope to get a new view of the sky, using gravitational wave detectors in addition to electromagnetic wave (light) telescope detectors. Fantastically difficult, because gravity is so much weaker than electromagnetism. Hope to see for example strong gravity effects, from sources like black holes and maybe some special events, like black hole collisions, and also in the early universe.

# Michelson Morley Expt:

1887. Used Michelson's interferometer to try to see the effect of earth's motion through the "ether".

"Ether" was the imagined stuff, filling all space, which allows light to propagate. Thought to be analogous to how sound waves require a medium, i.e. the air.

They did a careful experiment and found a negative result: no evident effect on the light from the earth's motion. Was explained by Einstein's 1905 theory of special relativity: there is no ether, and light's speed is unaffected by motion of the observer or source.