Announcements

- The first lab is tomorrow (Thursday)
  - no more reminders like this!

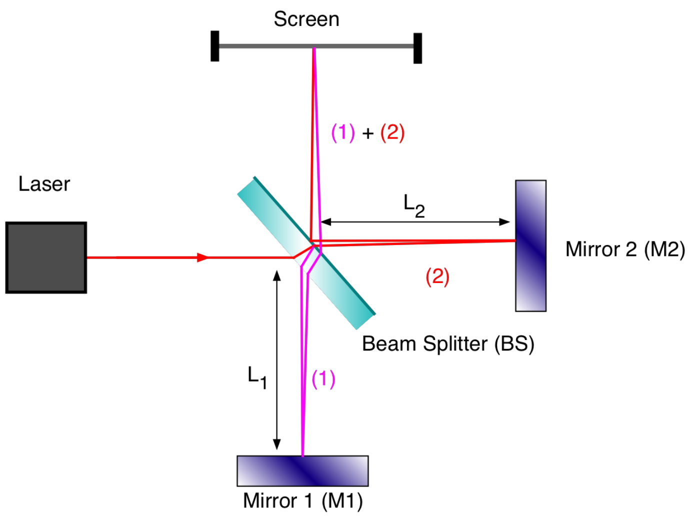
- First two homework assignments are due tomorrow (Thursday) at 8:00am
  - see smartPhysics for late turn-in deadline
  - no more reminders like this!

- Please check that your iClicker is correctly registered in the gradebook

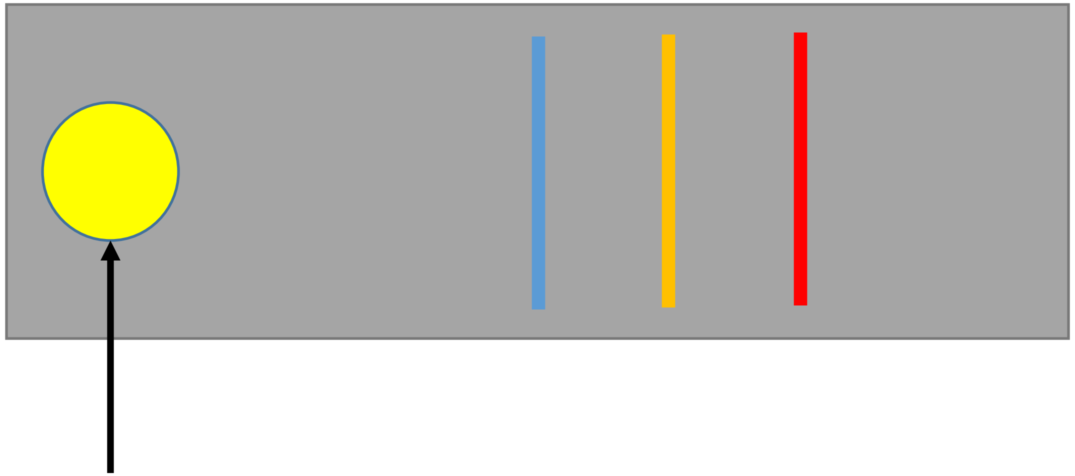
Are you able to access the office hour schedule?

	Sunday	Monday 279 Loomis	Tuesday 279 Loomis	Wednesday 279 Loomis	Thursday 279 Loomis	Friday	Saturday
8:00 AM							
9:00 AM							
10:00 AM			Ahmed Alenezi		Evangeline Wolanski		
11:00 AM				Brett Merriman	Lazar Kish		
12:00 PM							
1:00 PM		Nick Abboud or Siddharth Mansingh, depending on the week	Carlos Conde Ocazionez	Nick Abboud or Siddharth Mansingh, depending on the week			
2:00 PM			Tahereh Mozafarishamsi				
3:00 PM			Kannan Lu				

Practice with interference



Michaelson interferometer

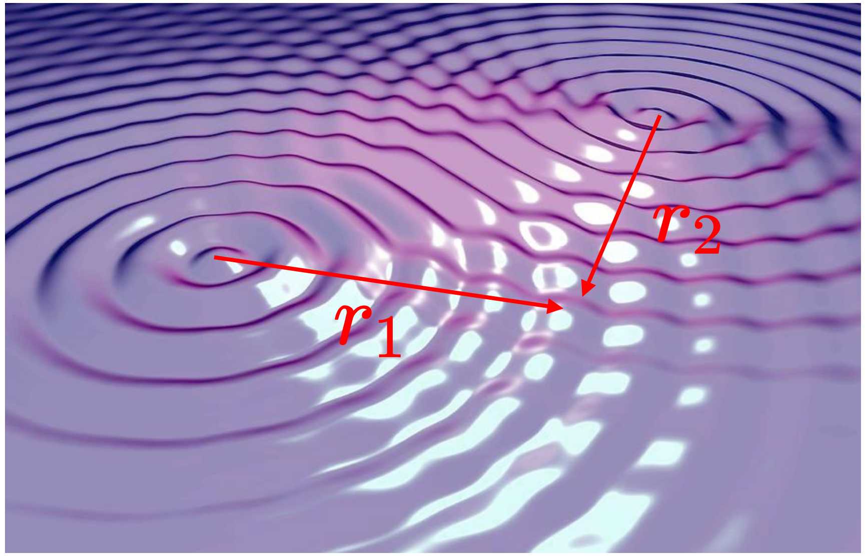


Light source

Diffraction grating

Phasors: here today, gone tomorrow

Interference between waves from two coherent monochromatic sources



$$y_1 = A_1 \cos(kr_1 - \omega t + \phi_1)$$

$$y_2 = A_2 \cos(kr_2 - \omega t + \phi_2)$$

$$y = y_1 + y_2$$

(superposition principle)

If $A_1 = A_2$, then

$$I = 2A_1^2 \cos^2\left(\frac{\Delta\phi}{2}\right)$$

$$\Delta\phi = \frac{2\pi(r_1 - r_2)}{\lambda} + \phi_2 - \phi_1$$

Constructive interference occurs when

$$\Delta\phi = 2\pi n$$

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

Destructive when

$$\Delta\phi = 2\pi\left(n + \frac{1}{2}\right)$$

If $A_1 \neq A_2$, then the phasor diagram tells us how to compute the intensity.

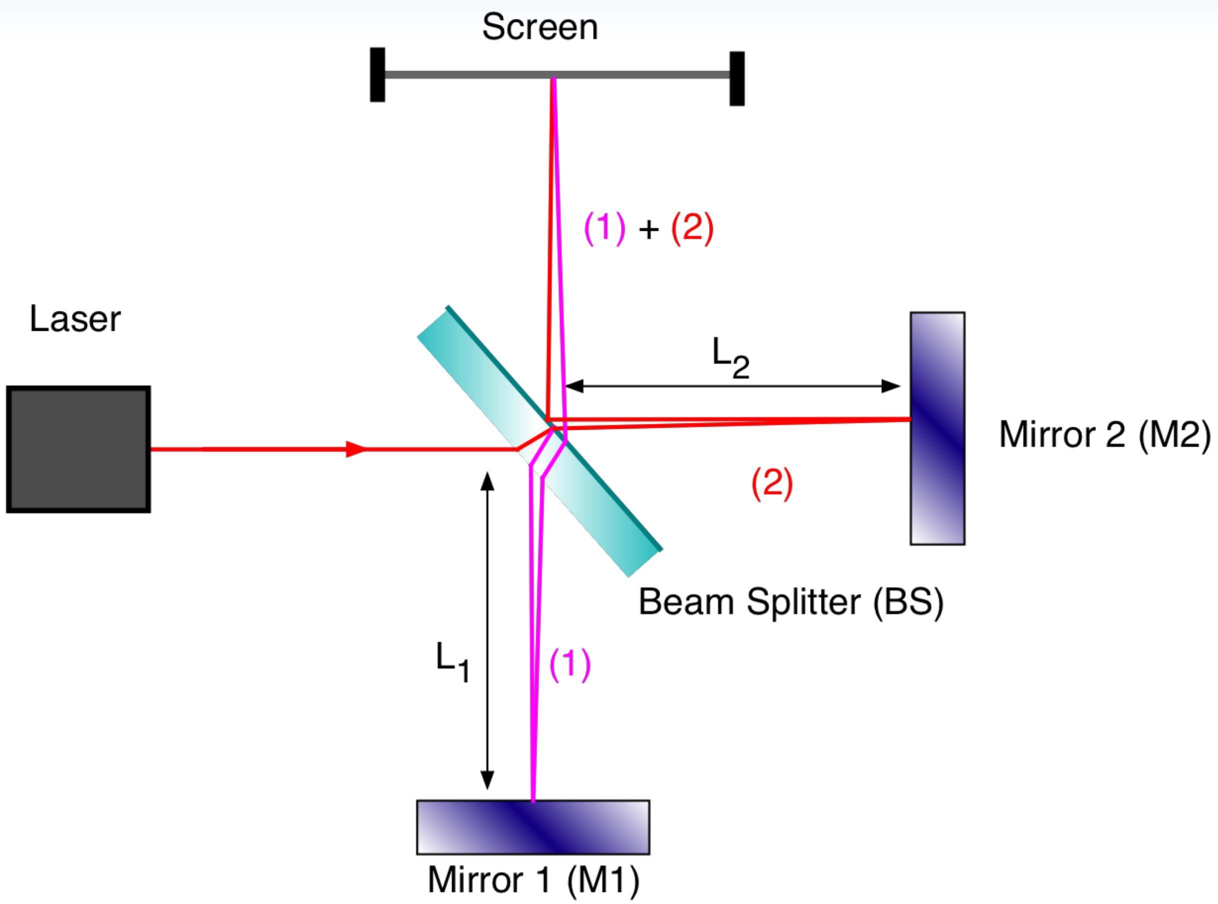
Remember, phasors represent oscillating quantities.

length of phasor <--> amplitude

angle of phasor wrt horizontal <--> phase (a.k.a. argument)

$$\cos(kr - \omega t + \phi) = \cos(\omega t - (kr + \phi))$$

Michaelson Interferometer

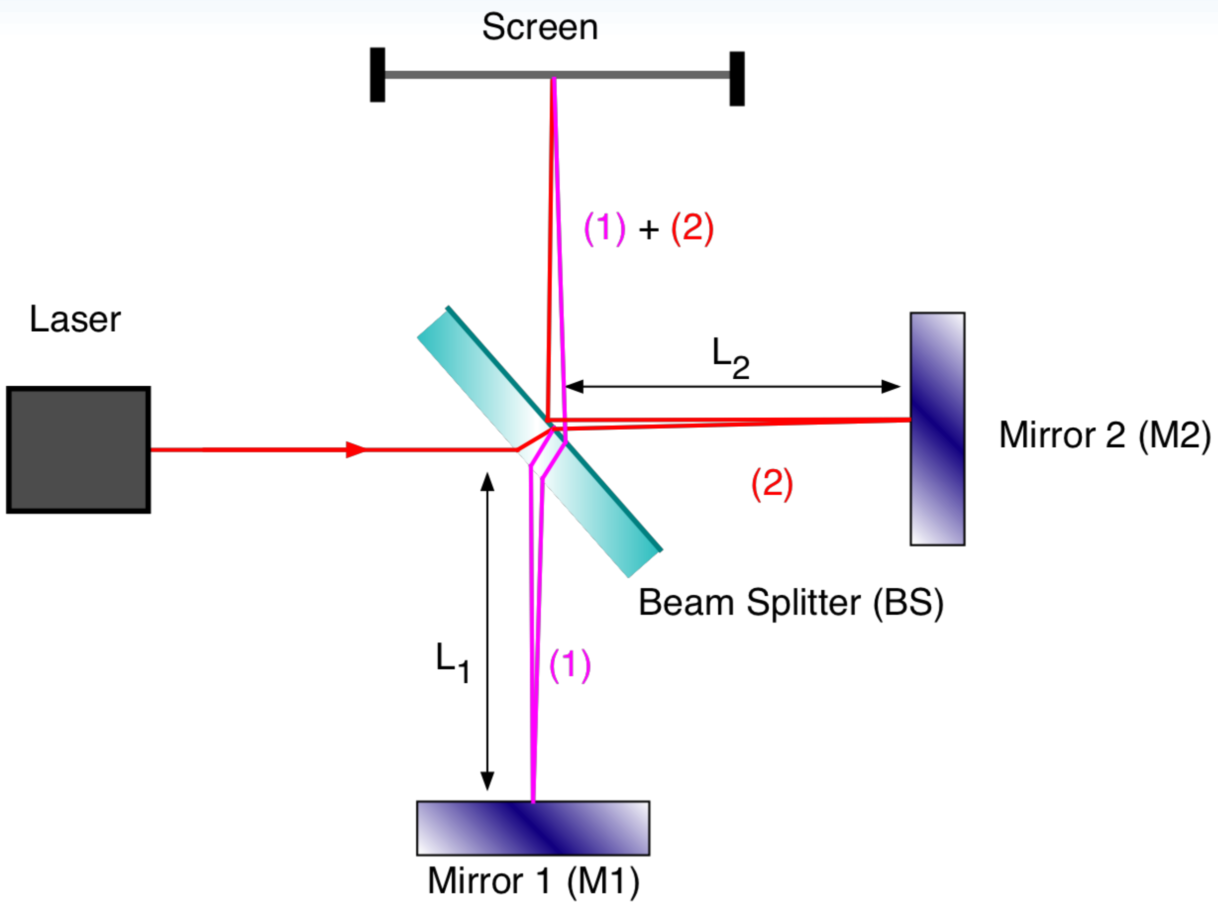


We know the lengths L_1 and L_2 of the arms.

What is r_2-r_1, the difference in path lengths?

A) L_2-L_1
B) $(L_2$-$L_1)/2$
C) $2(L_2$-$L_1)$
D) not enough info to determine

Michaelson Interferometer



Suppose the laser has wavelength λ. We observe constructive interference at the screen (maximal intensity). What is the phase difference between the two paths?

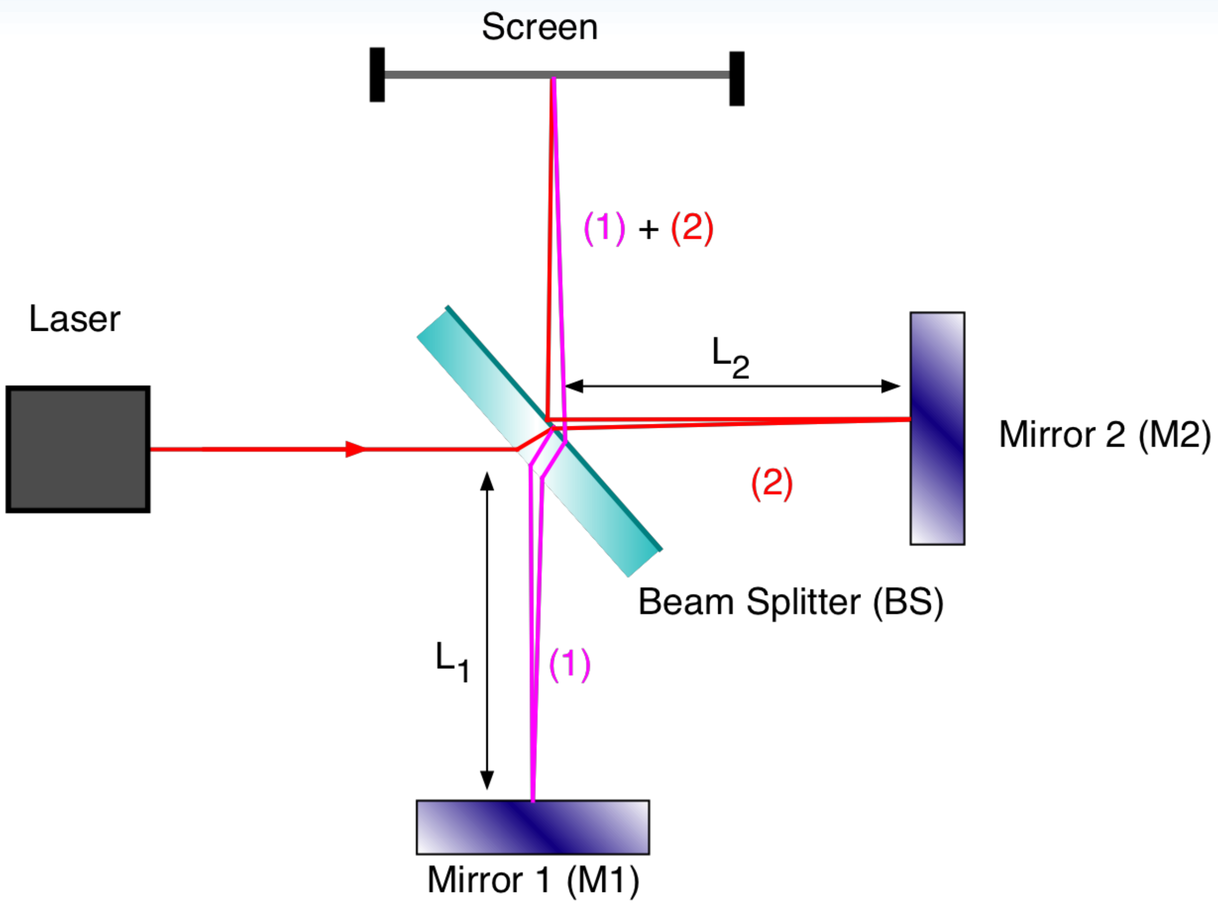
A) λn

B) $2\pi\left(n+\frac{1}{2}\right)$

C) $2\pi n$

D) $\lambda\left(n+\frac{1}{2}\right)$

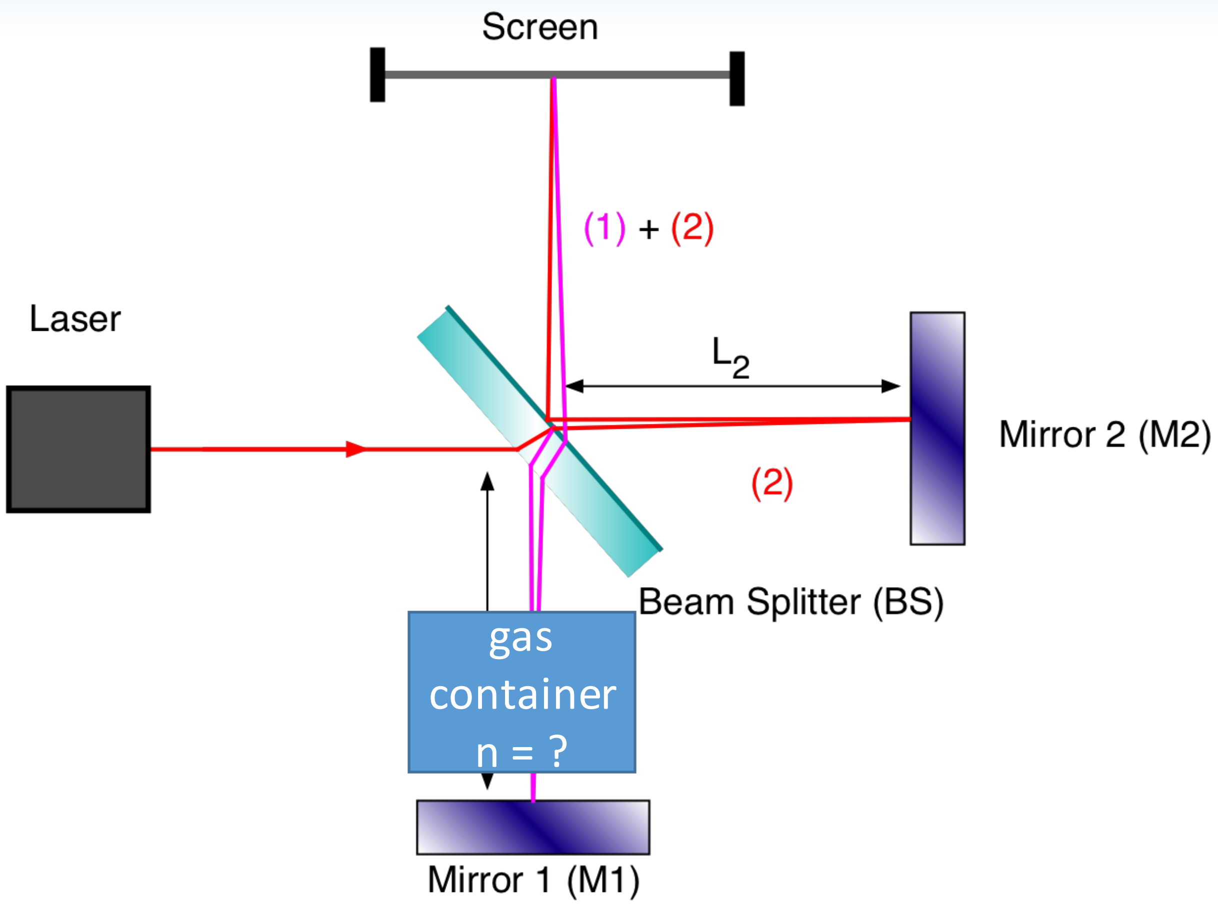
Michaelson Interferometer



Laser has wavelength λ. We observe maximal intensity at the screen. How far must we move mirror 1 to find the next maximum?

a) 2π
b) λ
c) π
d) $\frac{\lambda}{2}$

Example usage: measuring index of refraction



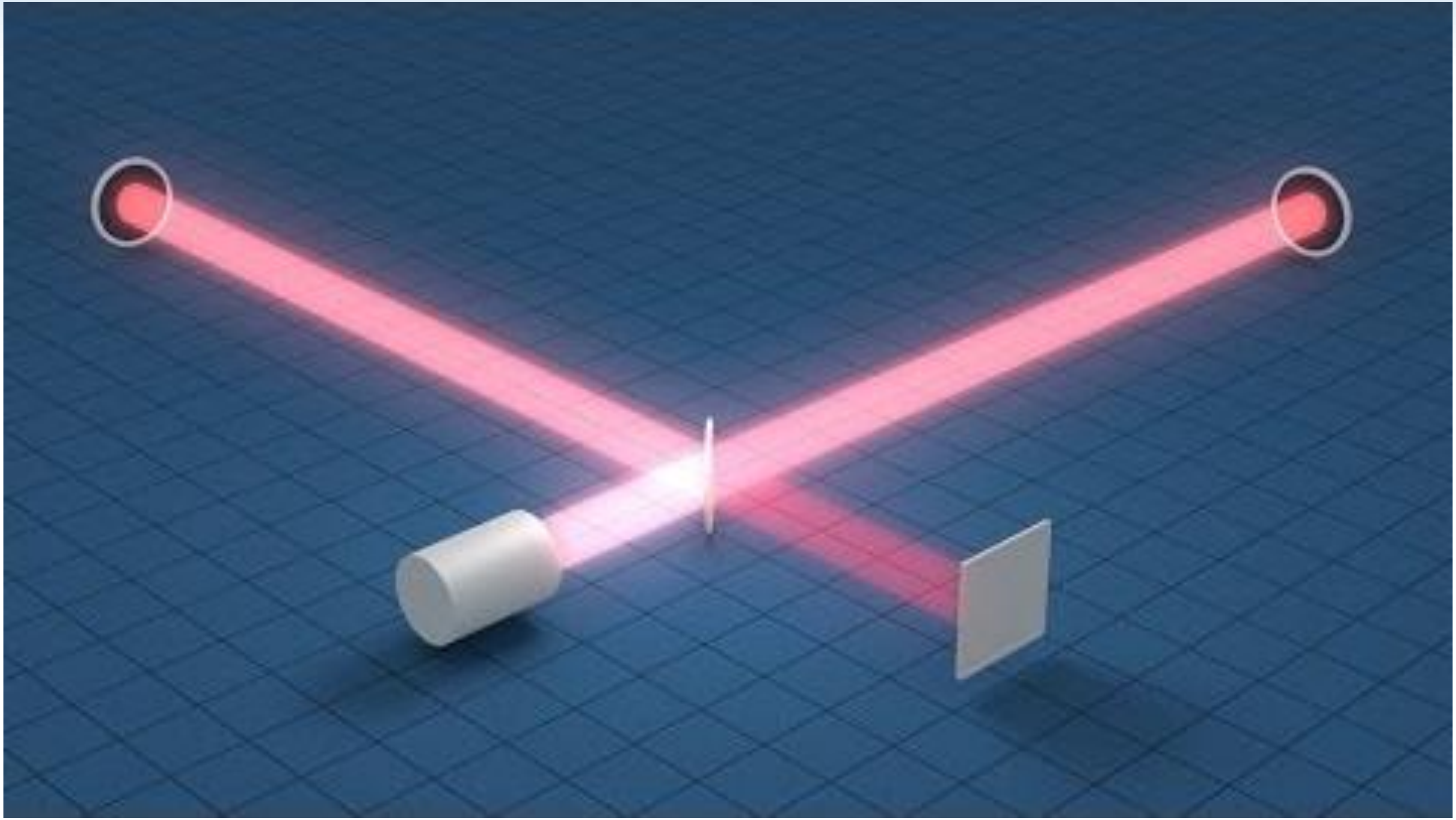
When light passes through the gas, it slows down, so its wavelength decreases.

==> MORE wavelengths now fit into the container

==> the interference pattern shifts

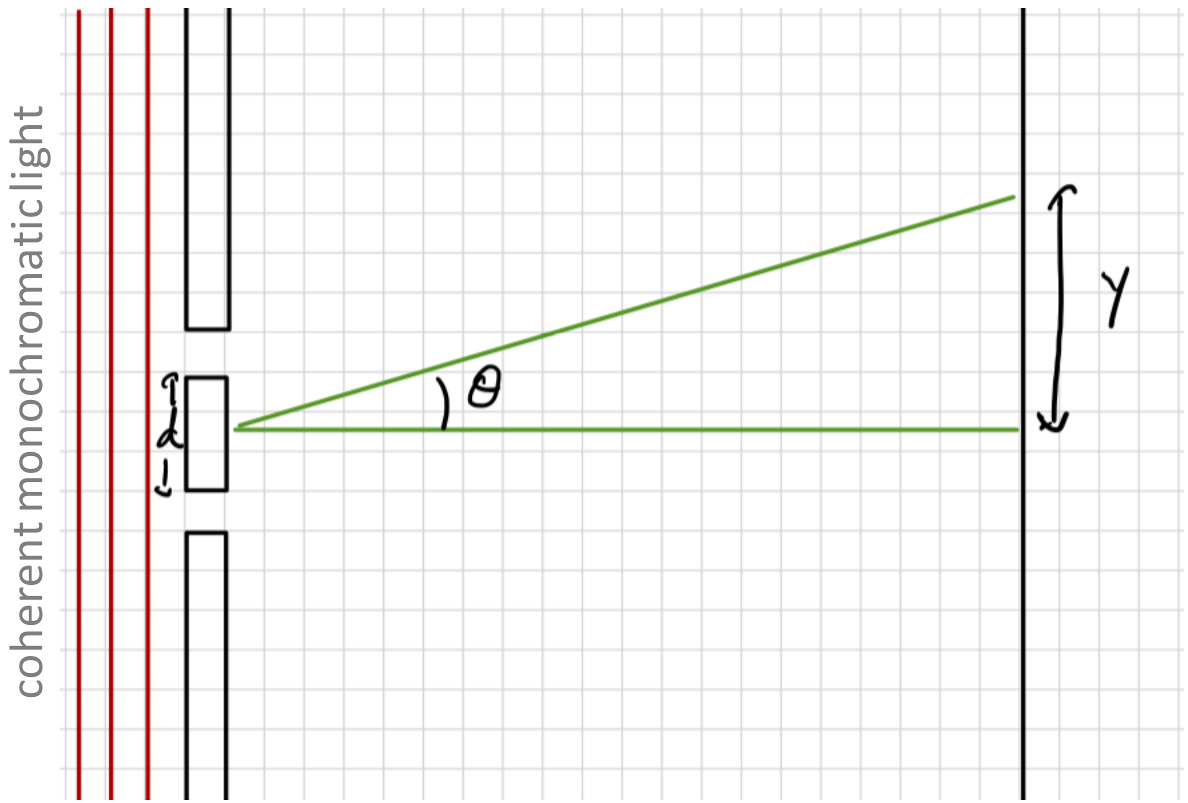
==> by measuring the shift, we can infer index of refraction n

Application: LIGO



https://youtu.be/tQ_teIUb3tE

Young's double-slit experiment



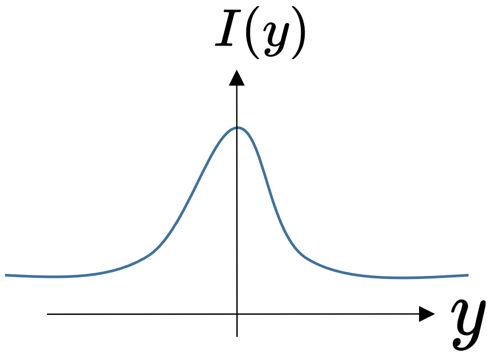
Newton vs. Huygens
(Corpuscles vs. Waves)

Who will emerge victorious??

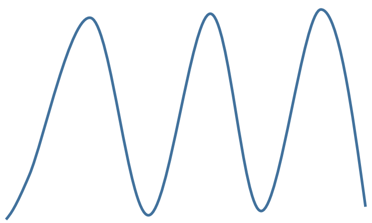
(Huygens will. But also Newton, in a way...)

Each slit acts as a source for coherent light of the same wavelength.

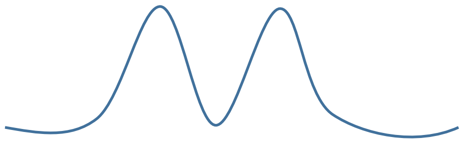
What do you expect to see for $I(y)$?



a) Isolated peak

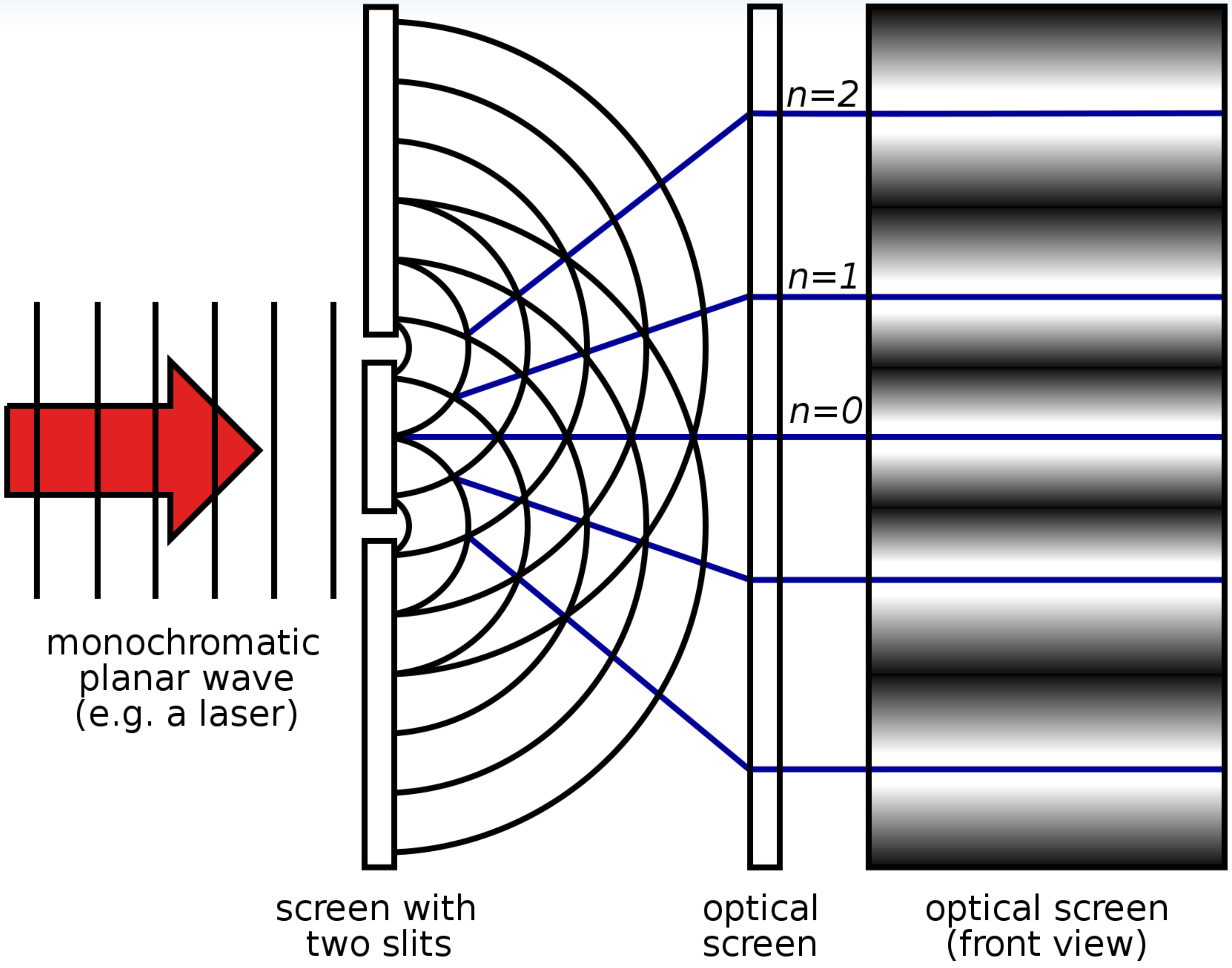


b) Repeating peaks

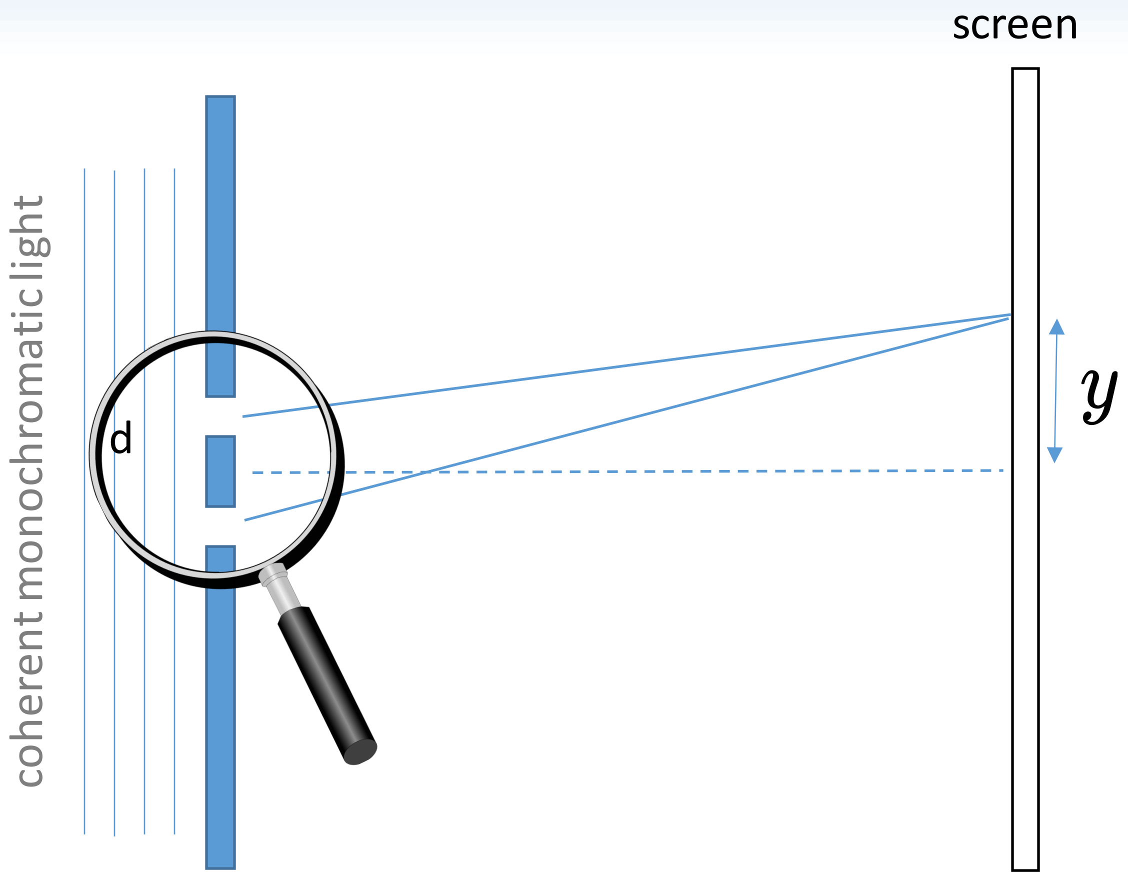


c) Two isolated peaks

Young's double-slit experiment

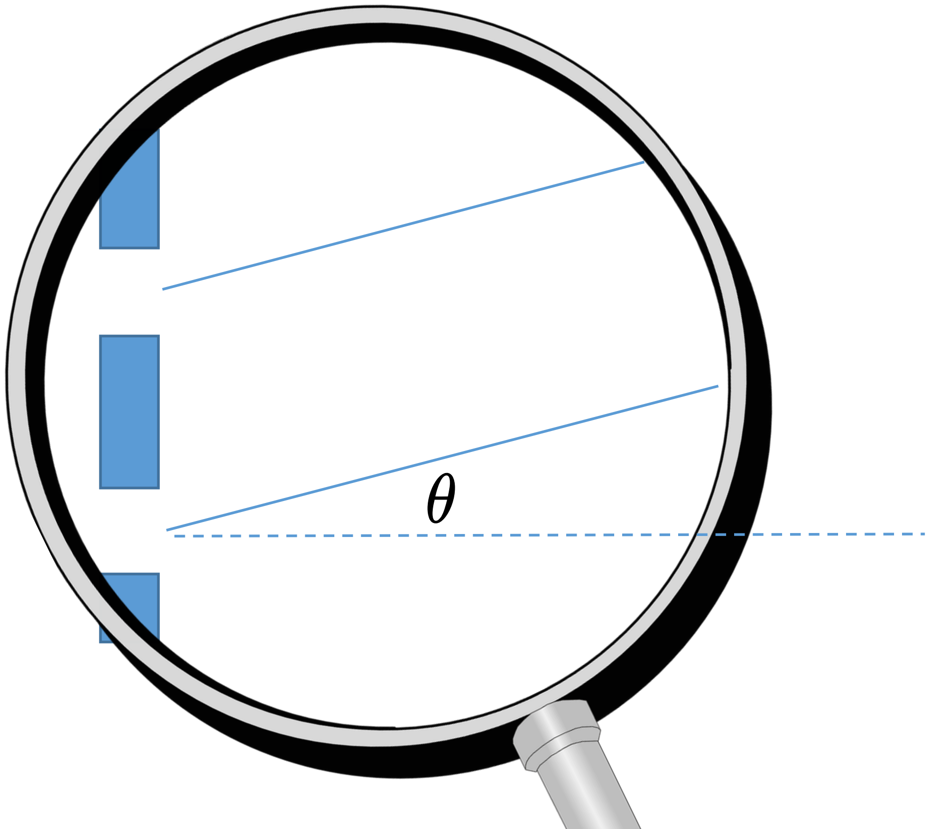


Young's double-slit experiment: geometry



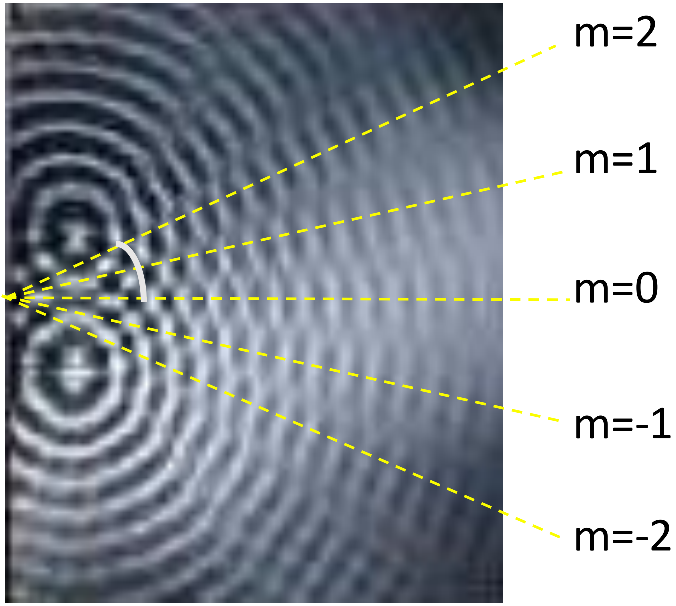
Approximation: L is very big compared to d.

$$L \gg d$$



$$r_2 - r_1 \approx d \sin \theta$$

Condition for constructive interference



For what values of $d \sin\theta$ does constructive interference occur?

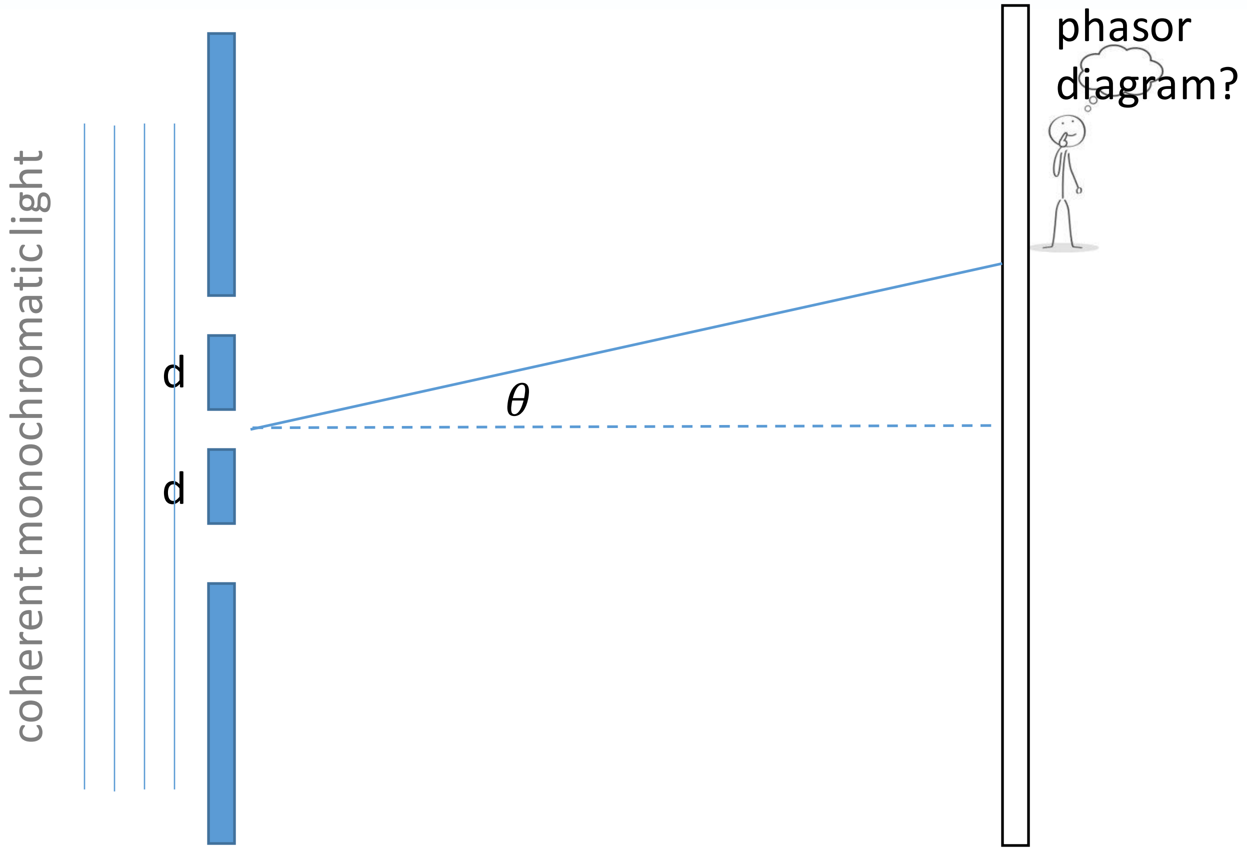
A) $n\lambda$

B) 2λ

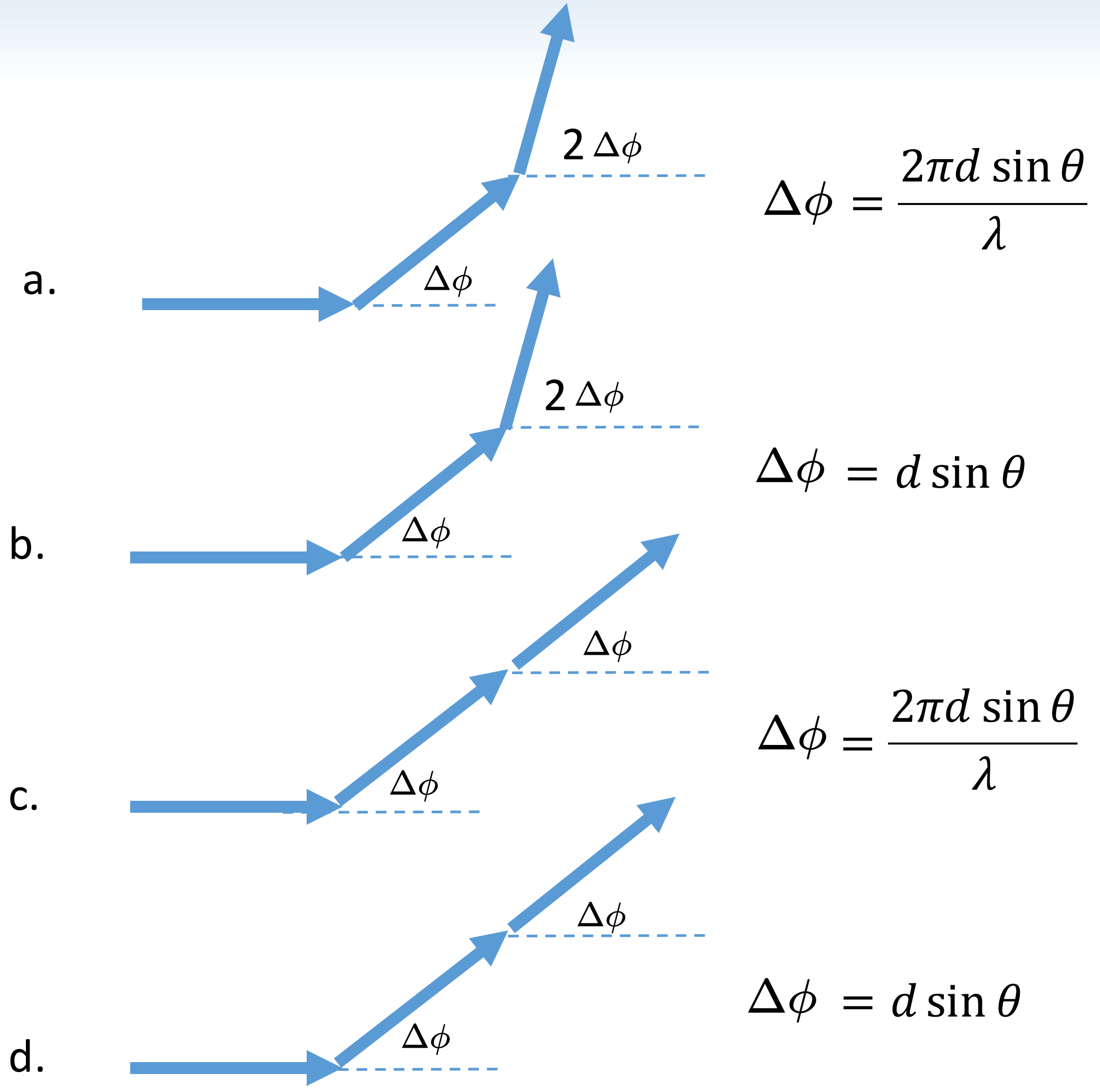
C) $2\pi n\lambda$

D) $2\pi n$

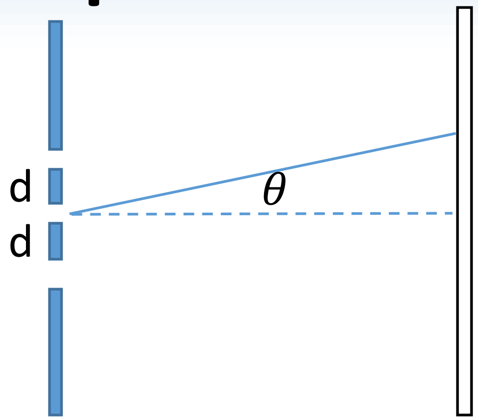
Multiple equally spaced slits/sources



a.k.a "diffraction grating"



Condition for constructive interference with multiple slits



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

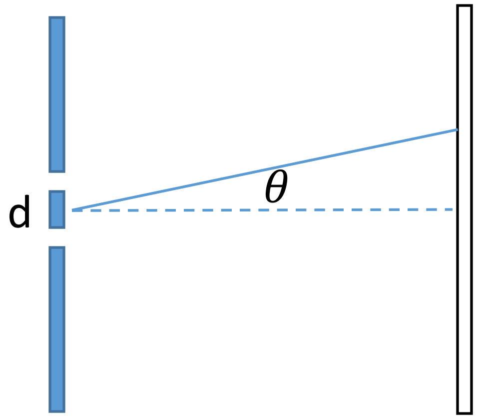
When there are two slits, the first intensity maximum is observed at $\theta_{\max}$

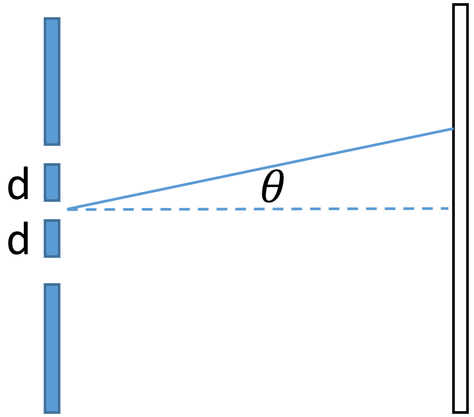
When there are three slits (same d, same λ), where will we find the first intensity maximum?

A) less than $\theta_{\max}$

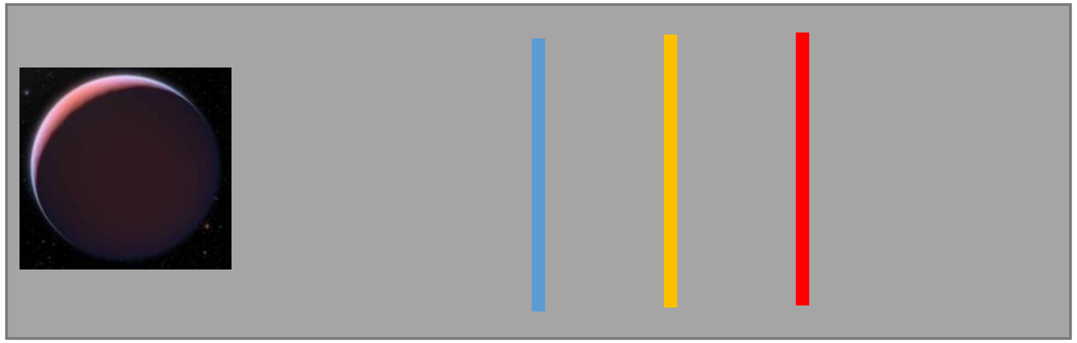
B) at $\theta_{\max}$

C) greater than $\theta_{\max}$



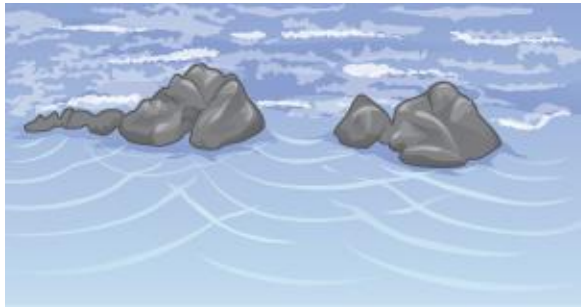


Application of diffraction gratings: spectroscopy

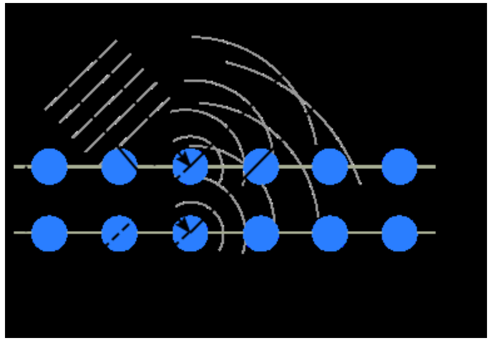


By looking at the spectral lines, we can measure what atoms are present in exoplanets! (know d, but don't know λ)

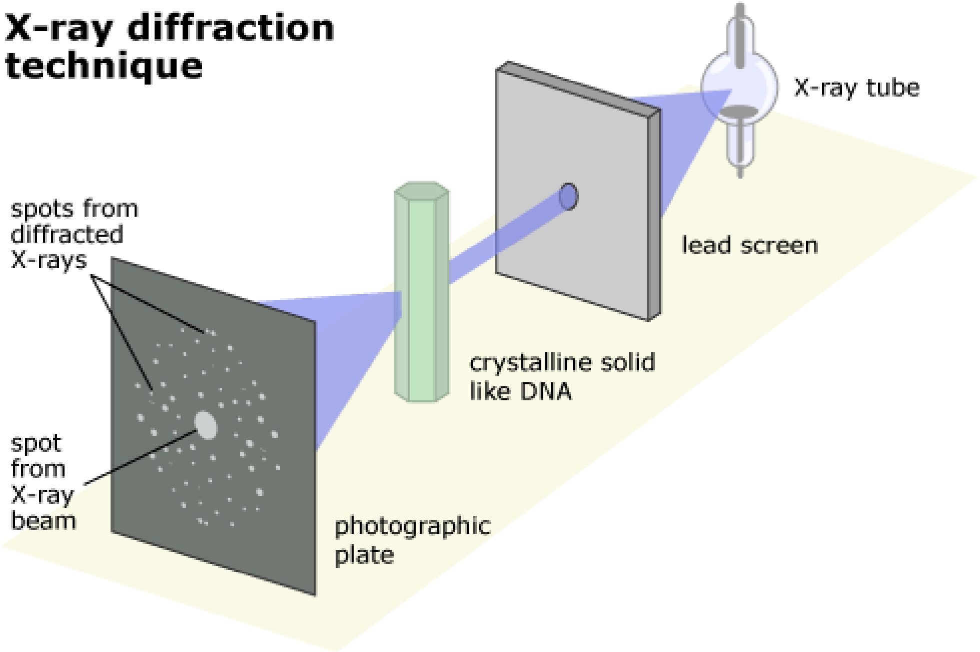
X-ray crystallography



Send x-ray known λ through a crystal, bounces off atoms ("sources") and we know the distances between atoms.

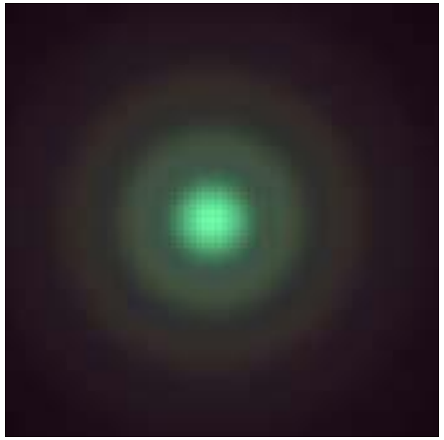


DNA's structure was discovered this way



Diffraction from a single aperture

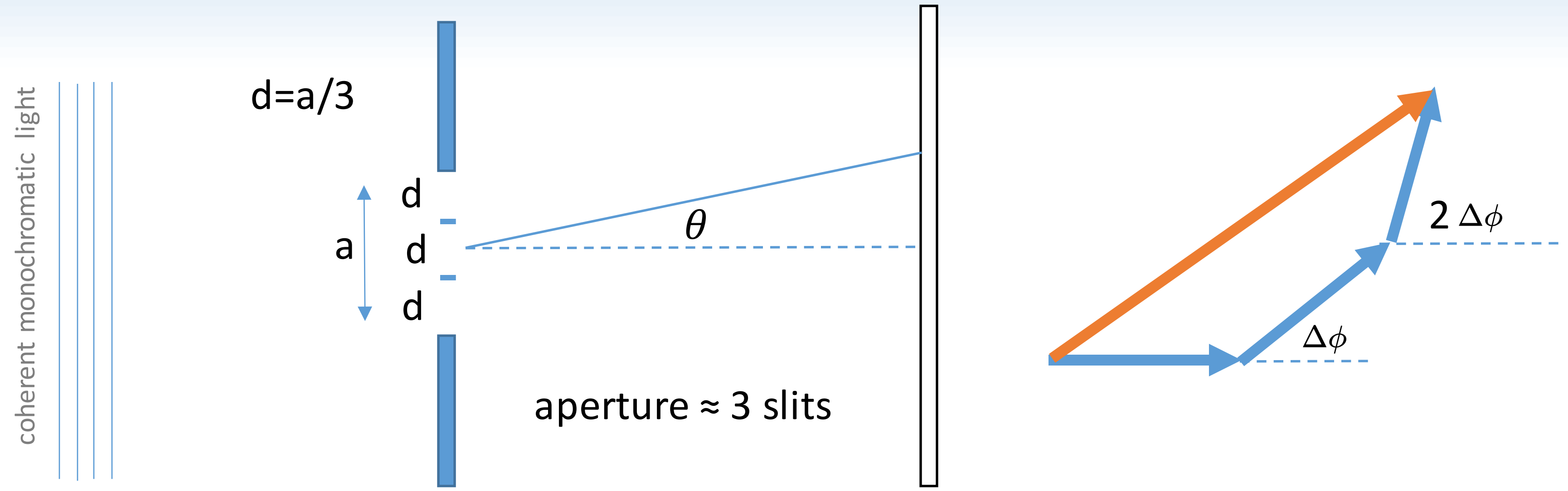
Diffraction: the spreading of waves around obstacles or upon passing through an aperture



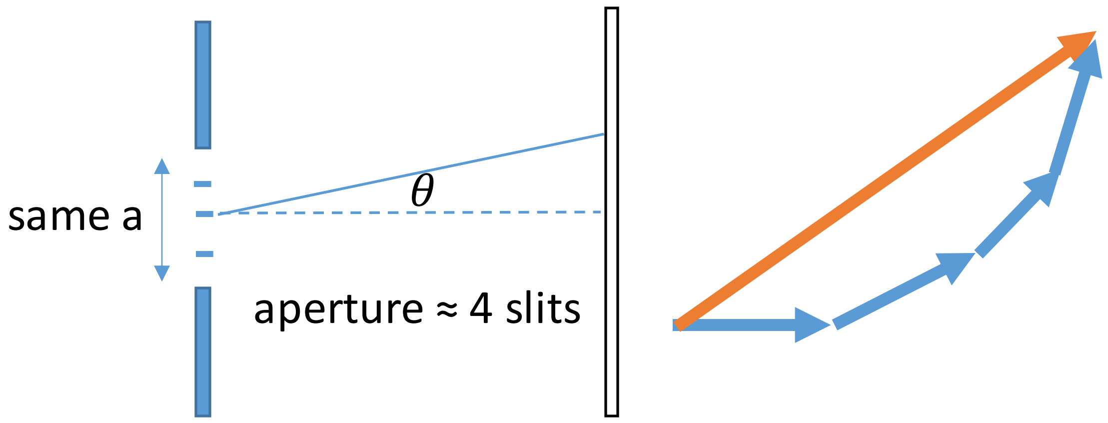
Diffraction: interference between multiple sources

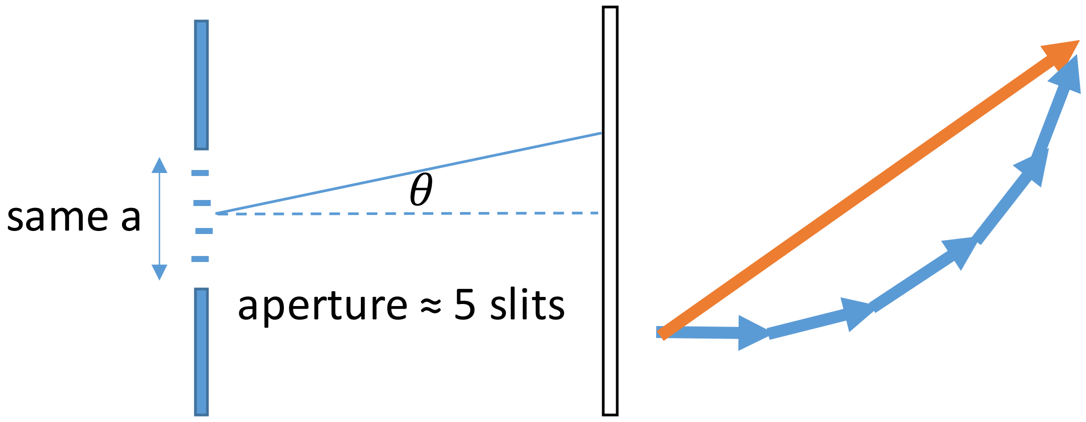
"that's the same thing" - Huygens

Multiple equally spaced slits --> aperture



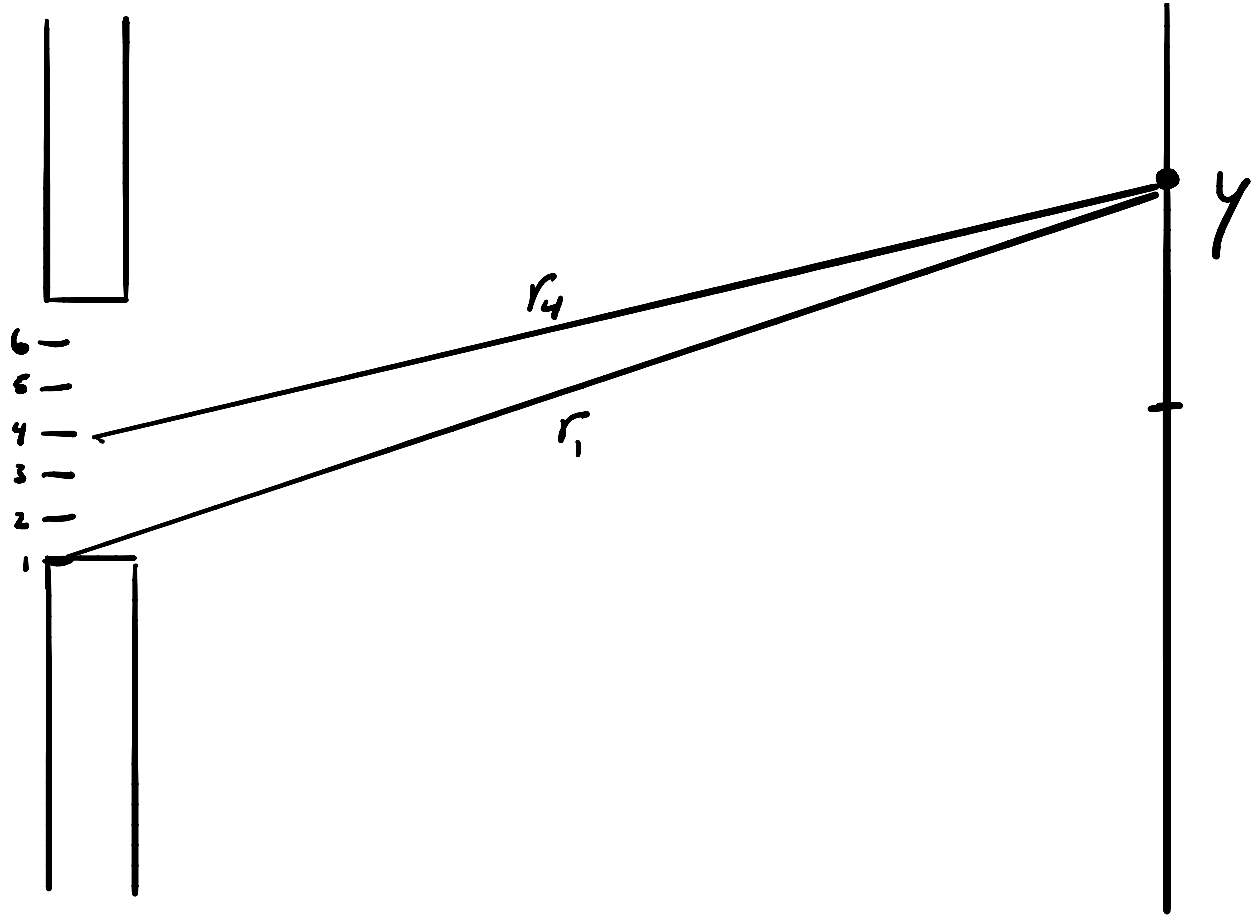
$$\Delta\phi = \frac{2\pi d \sin\theta}{\lambda}$$

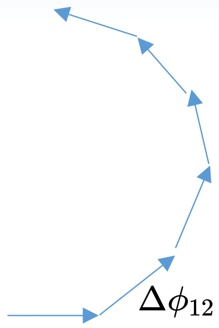




aperture = ∞ slits

6 slits: when do we get zero intensity?





$\Delta\phi_{12}$ = phase diff between waves arriving from adjacent slits

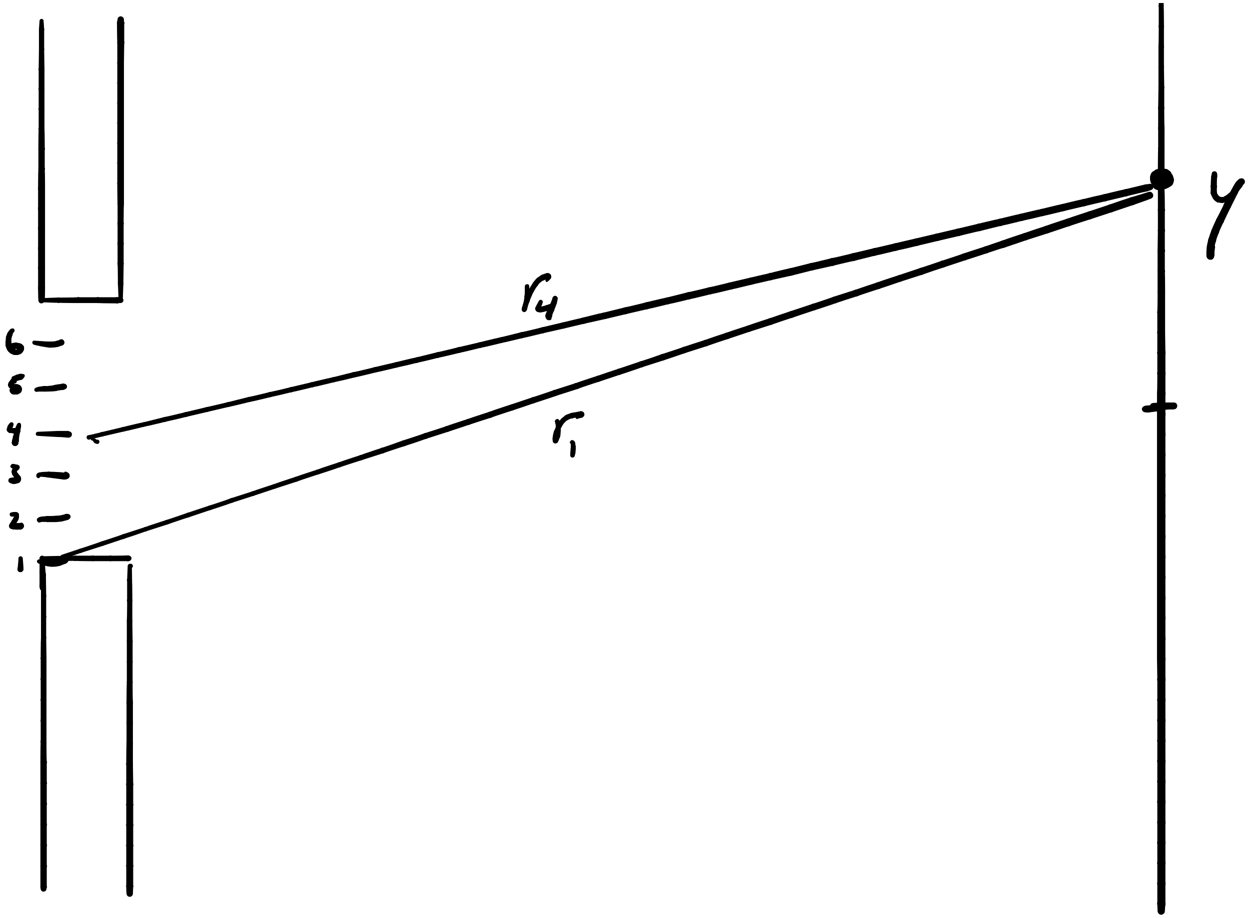
What is the smallest value of $\Delta\phi_{12}$ which makes the phasors sum to zero?

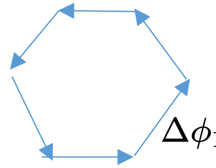
A) 2π

B) π

C) π/3

6 slits: when do we get zero intensity?





$$\Delta\phi_{12} = \frac{\pi}{3}$$

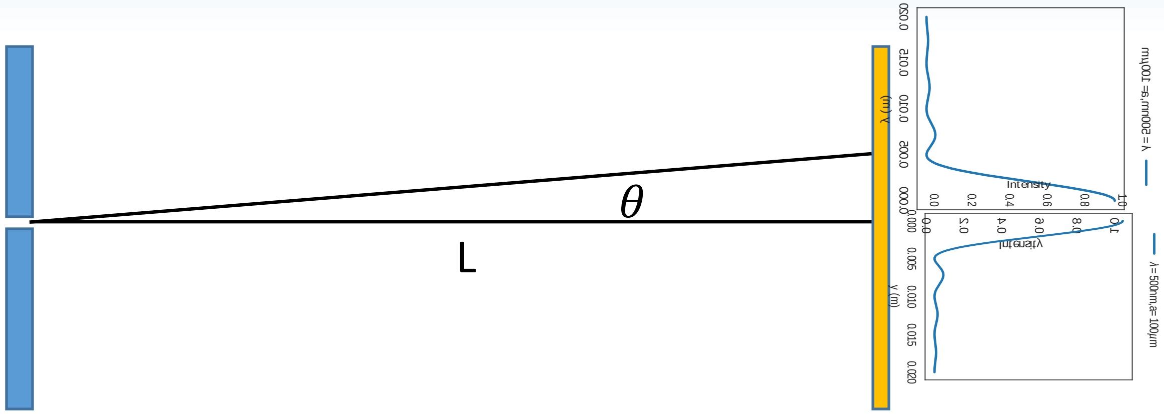
Which is the correct condition for the angle of the first diffraction minimum θ_{min} ?

A) $a \sin\theta_{\text{min}} = \lambda$

B) $a \sin\theta_{\text{min}} = 6\lambda$

C) $6a \sin\theta_{\text{min}} = \lambda$

Checkpoint question: spot size



$$\sin\theta_{min} = \frac{\lambda}{a}$$
$$y_{min} = L\tan\theta_{min}$$

Suppose a laser is incident on a small slit, which produces a spot on a screen a distance L away.

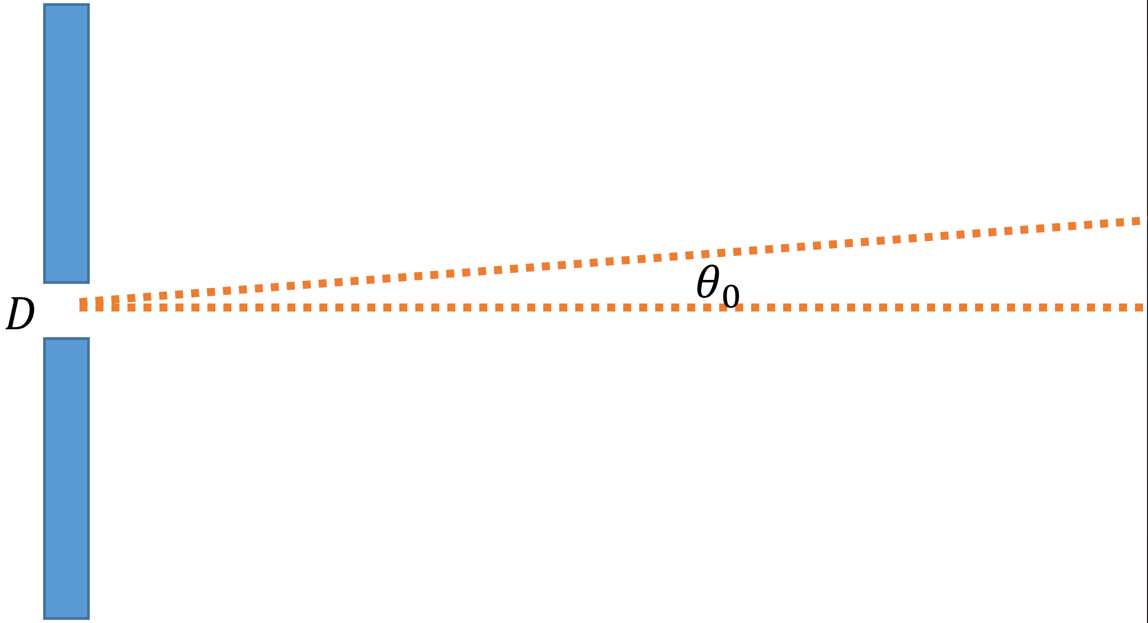
What would make the spot larger?

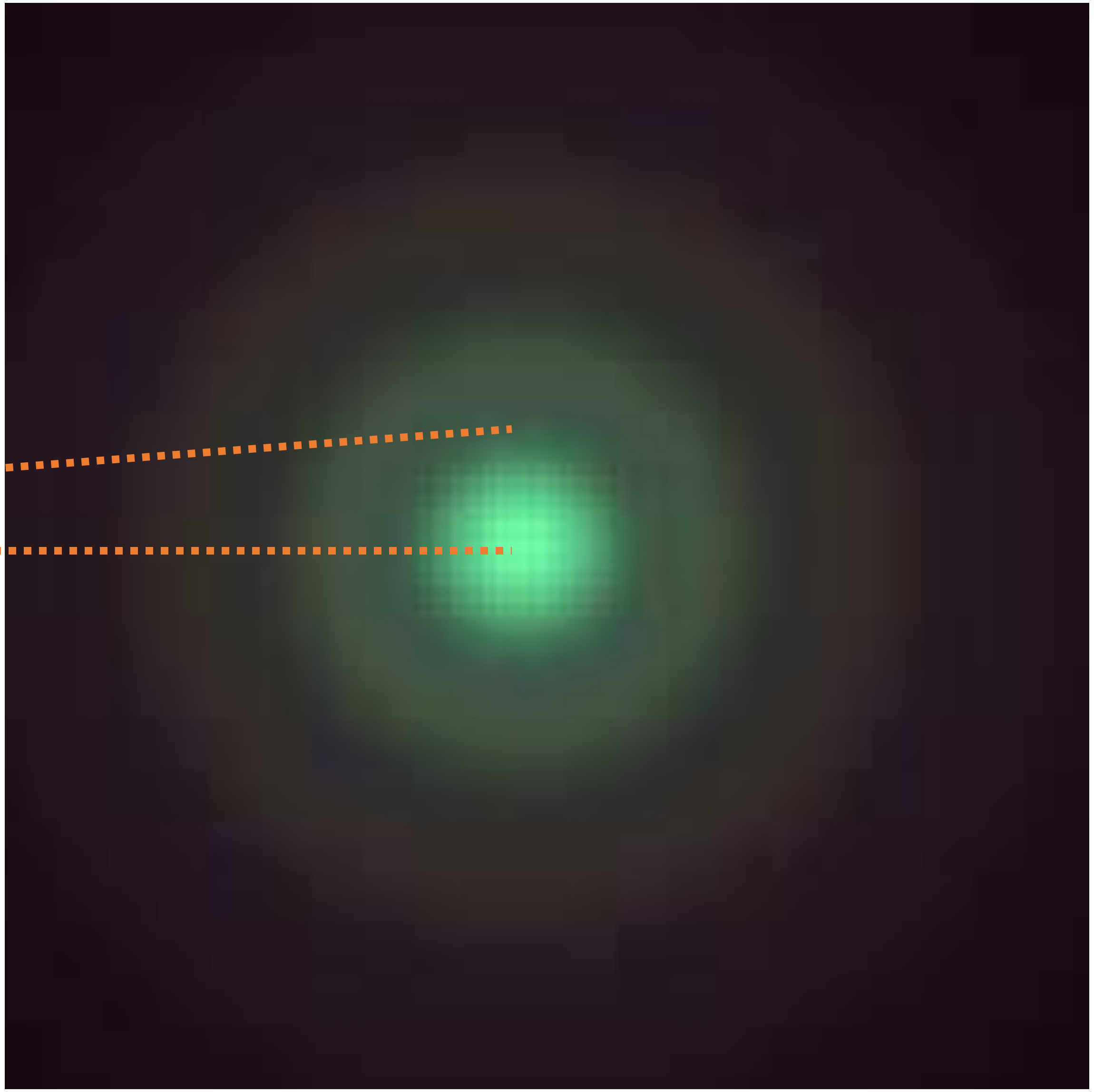
a) Move the screen closer to the slit.
b) Make the slit smaller.
c) Decrease the wavelength of the laser.

Spots from circular apertures

Circular apertures: Airy disk

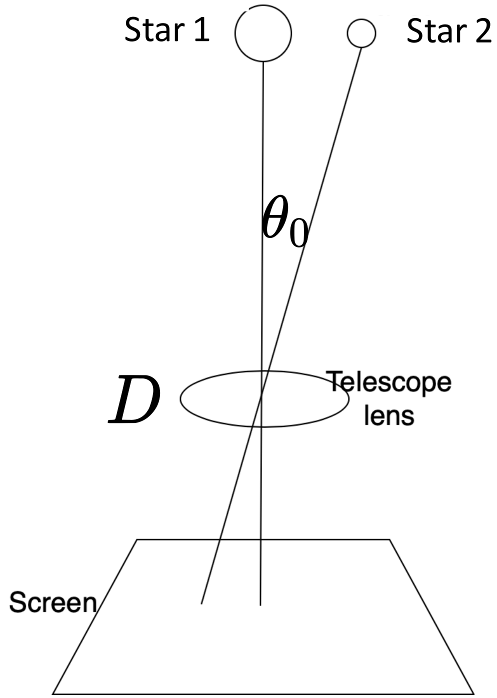
$$\sin\theta_0 = 1.22\frac{\lambda}{D}$$





Seeing stars: Beta Cygni (Albireo)

This photo shows the beautiful double star, Albireo, in Cygnus the Swan. Equipment used: Celestron C9.25 telescope and Casio QV8000SX digital camera
George Lilley



$$\sin\theta_0 = 1.22\frac{\lambda}{D}$$

Visible light $\lambda \approx 500\ \mathrm{nm}$

==> need $D > 4\ \mathrm{mm}$ at the bare minimum (Rayleigh criterion)

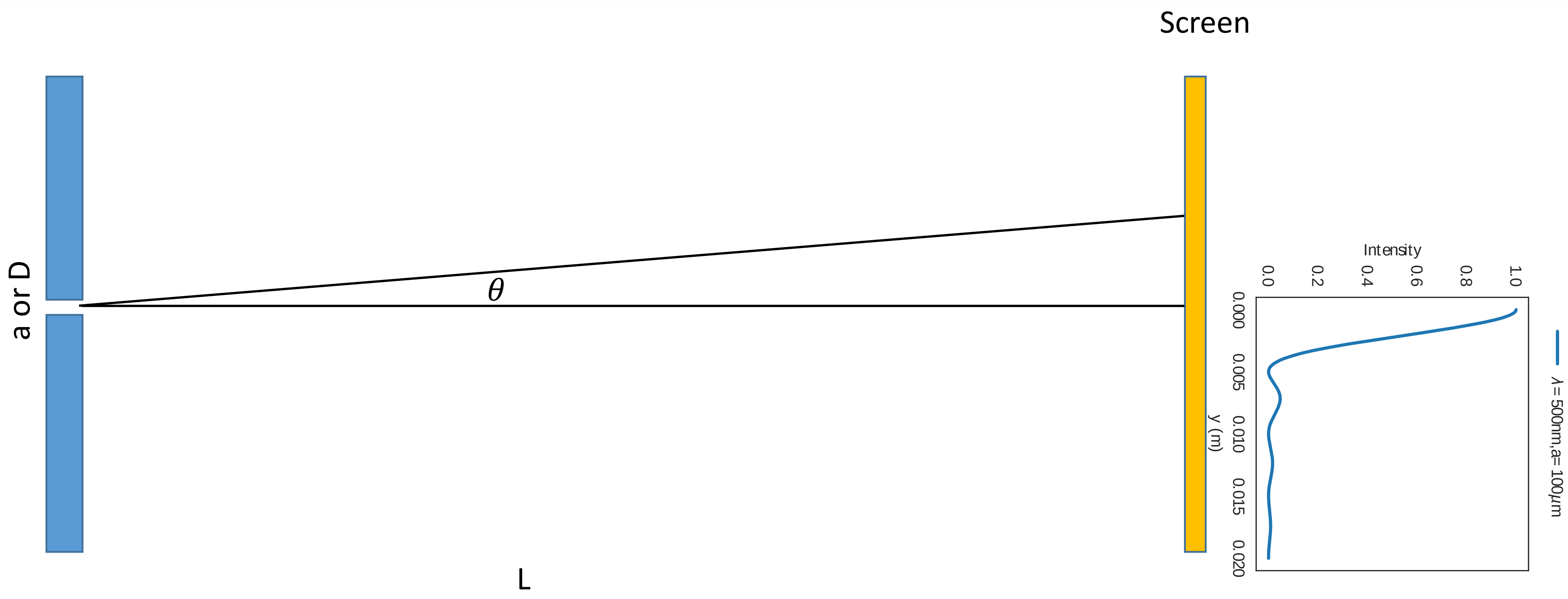
Angular separation
θ_0= 35.3’’ = 0.00017 radians

Big camera/small camera

If diffraction spots are too large, then features will bleed into each other and crisp images can't be resolved (like the screen here). What should you do to your camera aperture to avoid this effect?

a) Increase the aperture size
b) Decrease the aperture size
c) Doesn't matter

Summary



$$a \sin\theta_0 = \lambda$$
$$D \sin\theta_0 = 1.22\,\lambda$$
$$y = L \tan\theta$$