Essential Physics I

英語で物理学のエッセンス I

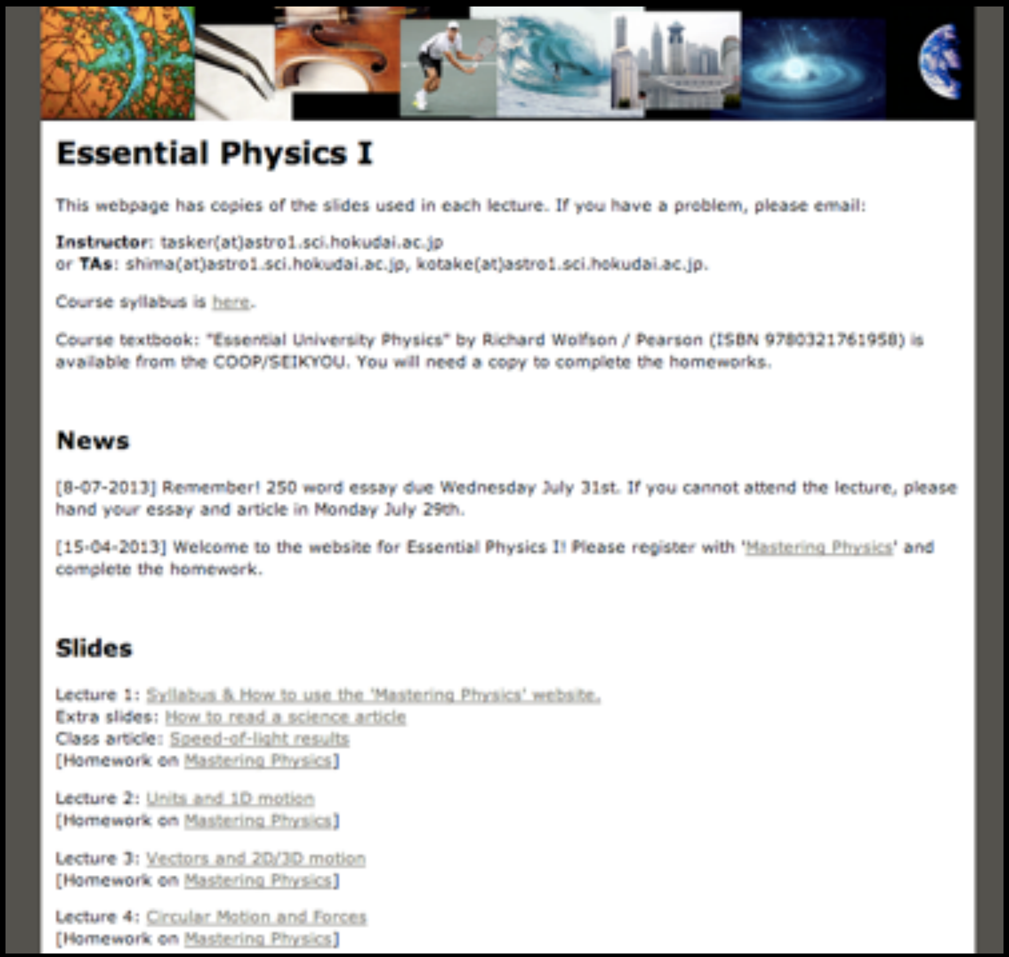
Lecture 14: 25-07-16

Exam

Next Lecture!
(1 week)

All lecture slides on course website:

http://astro3.sci.hokudai.ac.jp/~tasker/teaching/ep1



Essential Physics I

This webpage has copies of the slides used in each lecture. If you have a problem, please email:

Instructor: tasker(at)astro1.sci.hokudai.ac.jp
or **TAs**: shima(at)astro1.sci.hokudai.ac.jp, kotake(at)astro1.sci.hokudai.ac.jp.

Course syllabus is here.

Course textbook: "Essential University Physics" by Richard Wolfson / Pearson (ISBN 9780321761958) is available from the COOP/SEIKYOU. You will need a copy to complete the homeworks.

News

[8-07-2013] Remember! 250 word essay due Wednesday July 31st. If you cannot attend the lecture, please hand your essay and article in Monday July 29th.

[15-04-2013] Welcome to the website for Essential Physics I! Please register with 'Mastering Physics' and complete the homework.

Slides

Lecture 1: Syllabus & How to use the 'Mastering Physics' website.
Extra slides: How to read a science article
Class article: Speed-of-light results
[Homework on Mastering Physics]

Lecture 2: Units and 1D motion
[Homework on Mastering Physics]

Lecture 3: Vectors and 2D/3D motion
[Homework on Mastering Physics]

Lecture 4: Circular Motion and Forces
[Homework on Mastering Physics]

Remember your calculator!

Dictionary is OK!
(Phone is not)

SHOW ALL WORKING!

Next week's exam

10 multiple choice questions

(A) .....

(B) .....

(C) .....

(D) .....

- ~6 classical mechanics
- ~2 oscillations, waves & fluids
- ~2 optics

Homework	40 %
Attendance / clickers	20 %
Exam	40 %
Total	100 %

- Pass > 60 %

Next week's exam

This is a question.

(A) .....

(B) .....

(C) .....

(D) .....

If this is wrong....

You will get marks!

SHOW YOUR WORKING!

$$x = x_0 + ut + \frac{1}{2}at^2$$

$$t = \frac{-u \pm \sqrt{u^2 - 4(a/2)(x_0 - x)}}{a}$$

$$= \frac{-12 \pm \sqrt{144 - 4(9.81/2)(17)}}{9.81}$$

But parts of this are right...

Last week: Mirrors & Lenses

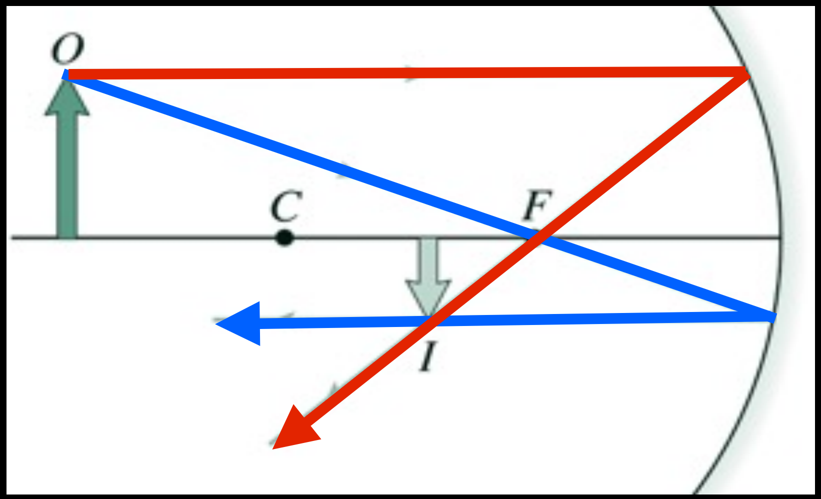


Image position can be found by drawing 2 light rays from points on the object.

Rays touch a real image

Last week: Mirrors & Lenses

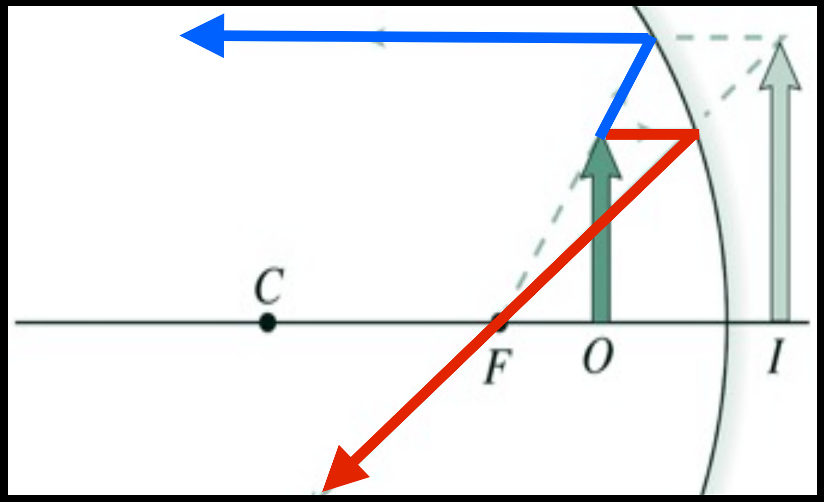
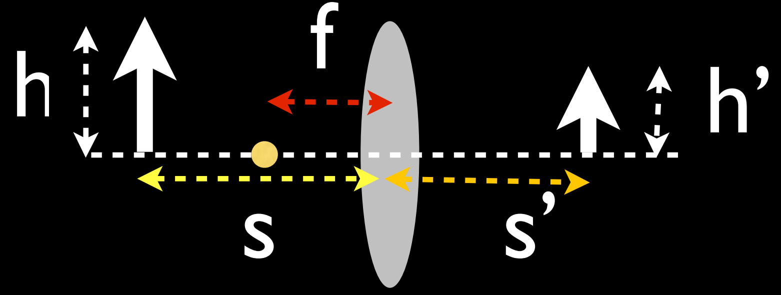


Image position can be found by drawing 2 light rays from points on the object.

Rays touch a real image

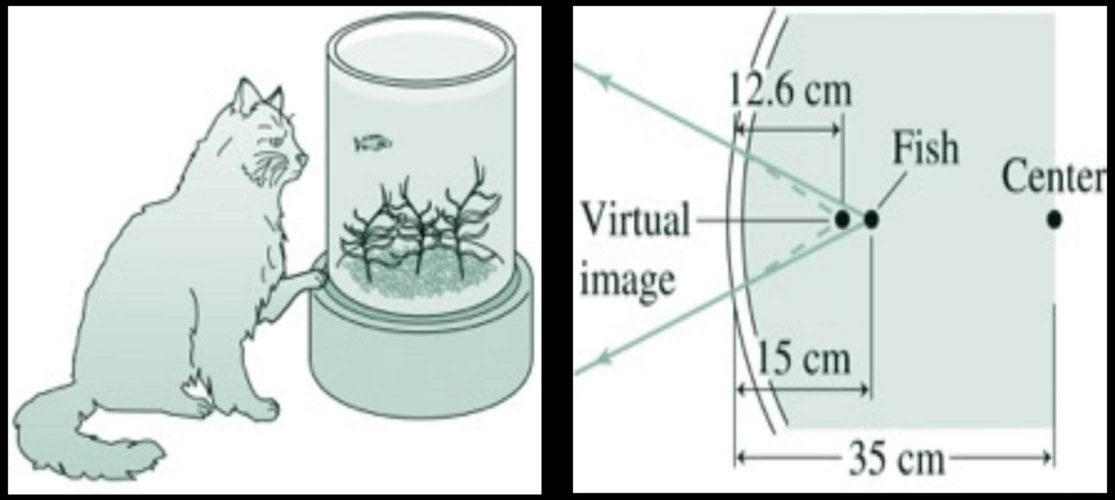
Rays only appear to touch a virtual image

Magnification: $$M = \frac{h'}{h} = -\frac{s'}{s}$$



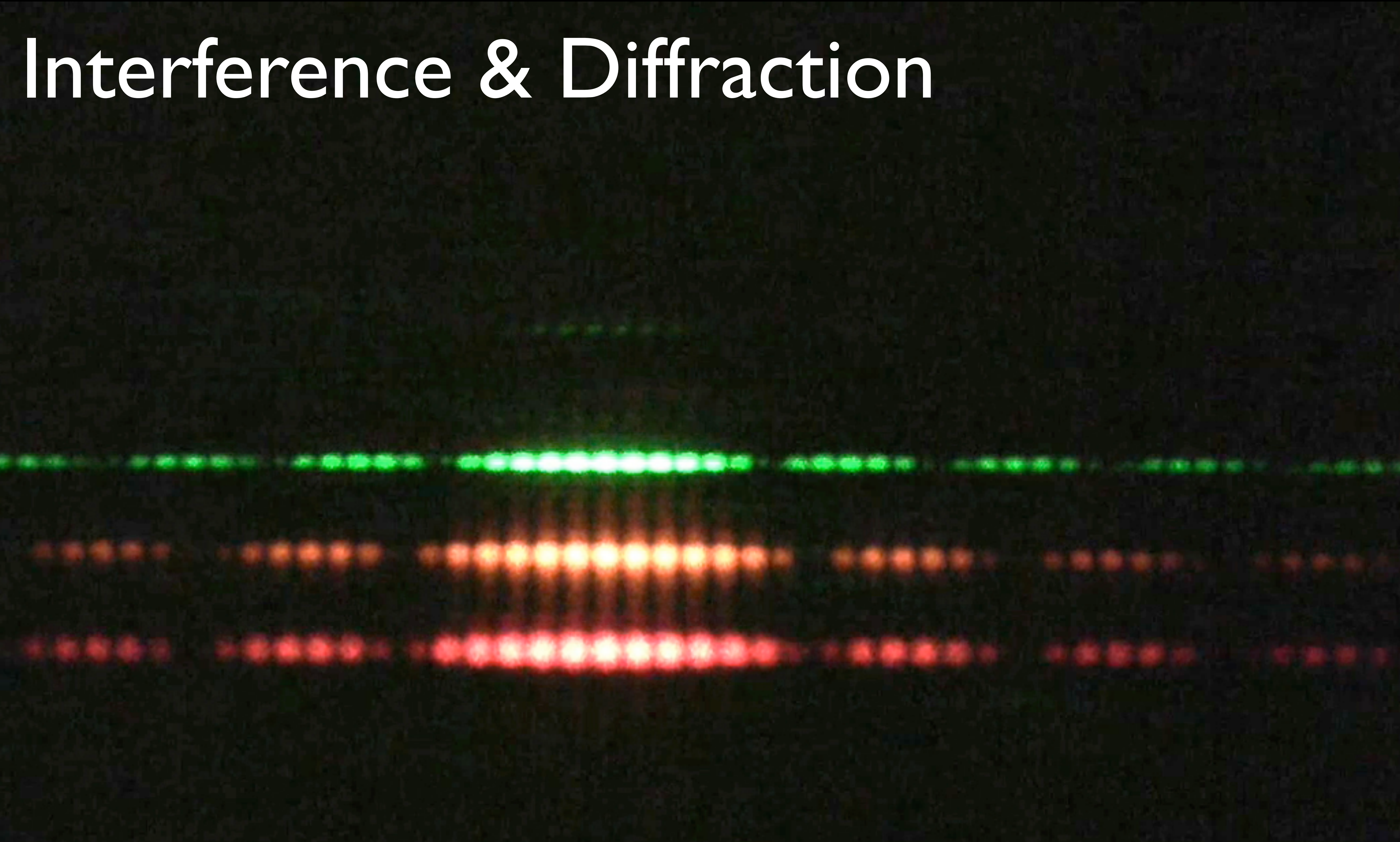
Mirror/Lens equation: (thin lenses) $$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

Inside a lens: $$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R}$$

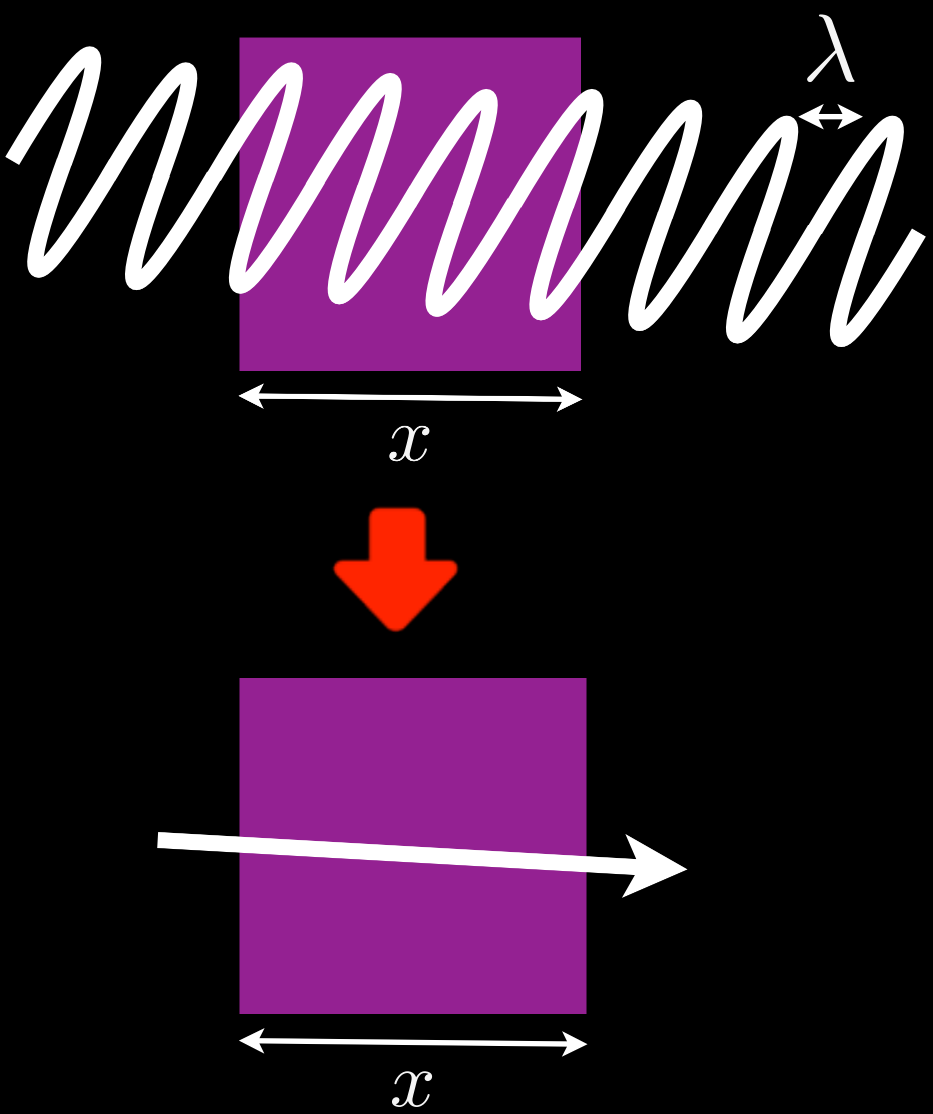


Optics

Interference & Diffraction



So far...



We assumed:

Light travels in a straight line: a ray

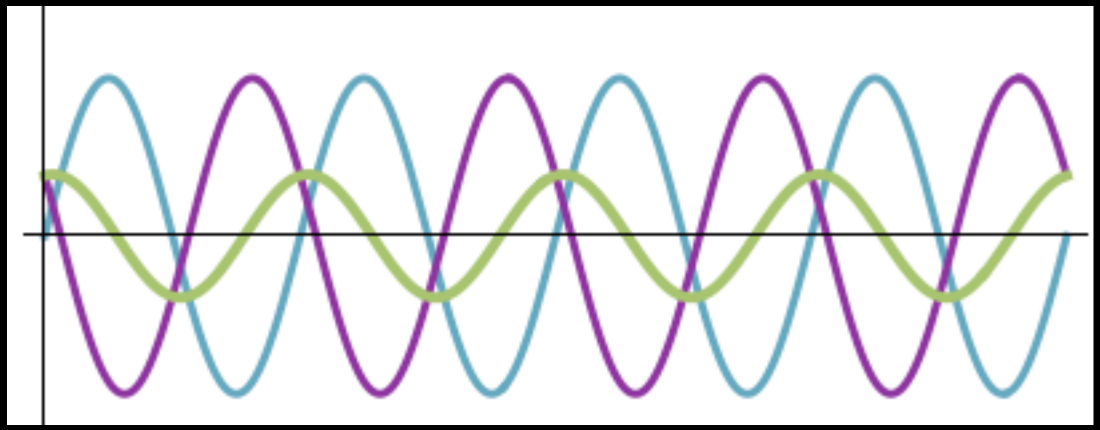
(Geometrical optics)

$$\lambda << x$$

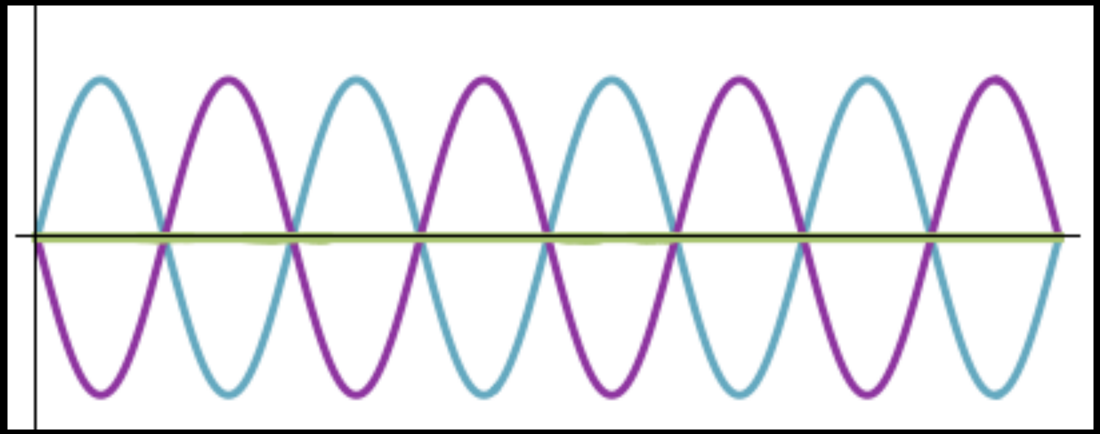
But, sometimes the wave nature of light is very important.

Interference and diffraction

Lecture 10: waves add

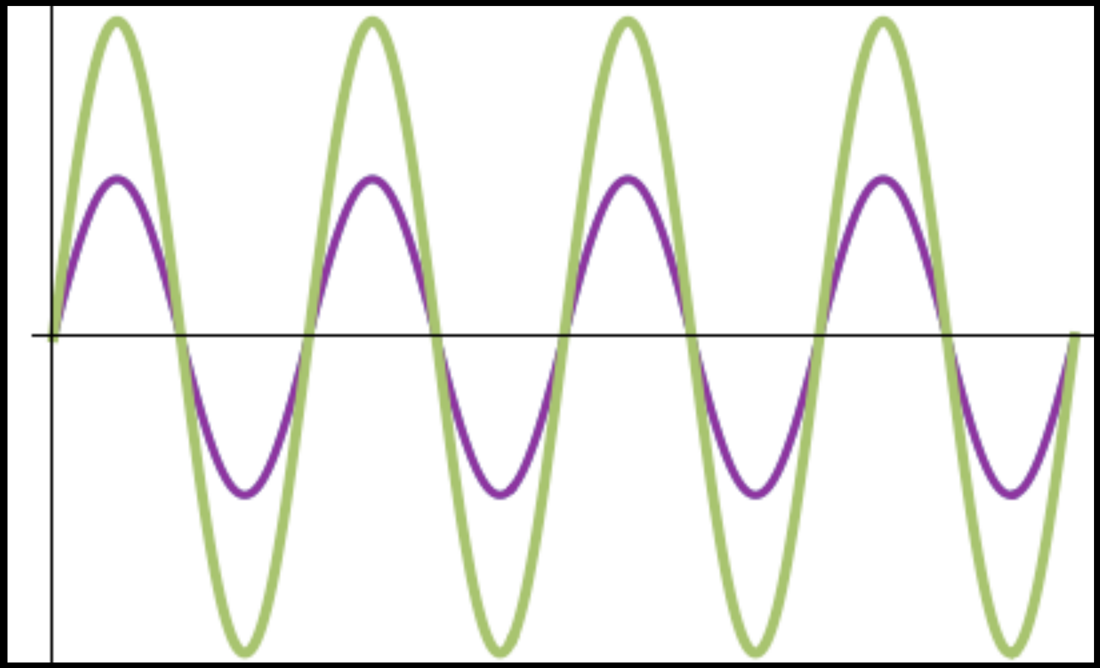


wave 1 + wave 2 = resulting wave



wave 1 + wave 2 cancel

Destructive interference



waves coincide

Constructive interference

Light waves are the same.

Coherence

For continuous interference, waves must be coherent.

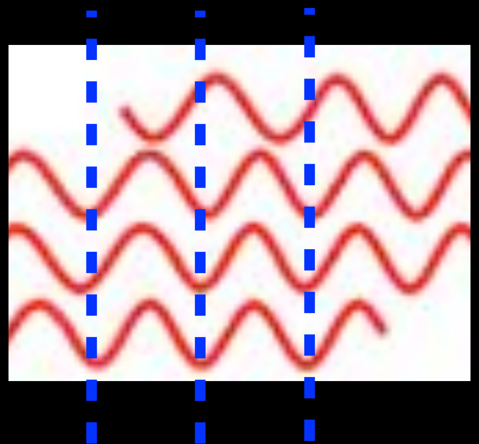
e.g. always constructive or

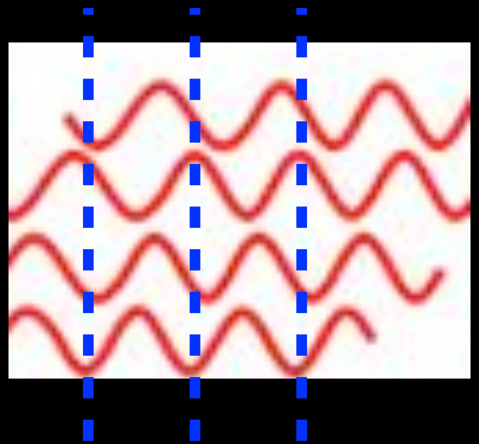
always destructive or

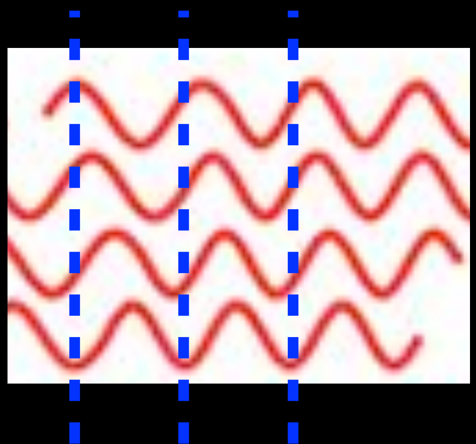
always ….

Coherence

For continuous interference, waves must be coherent.

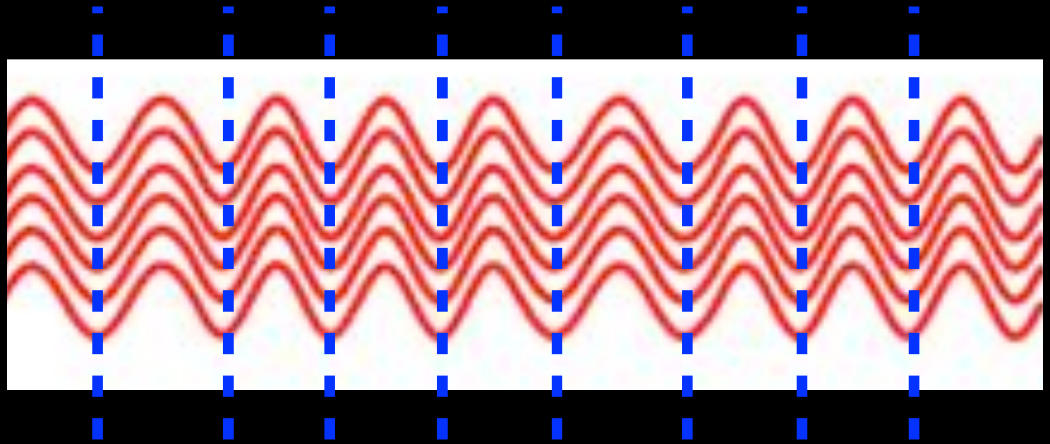




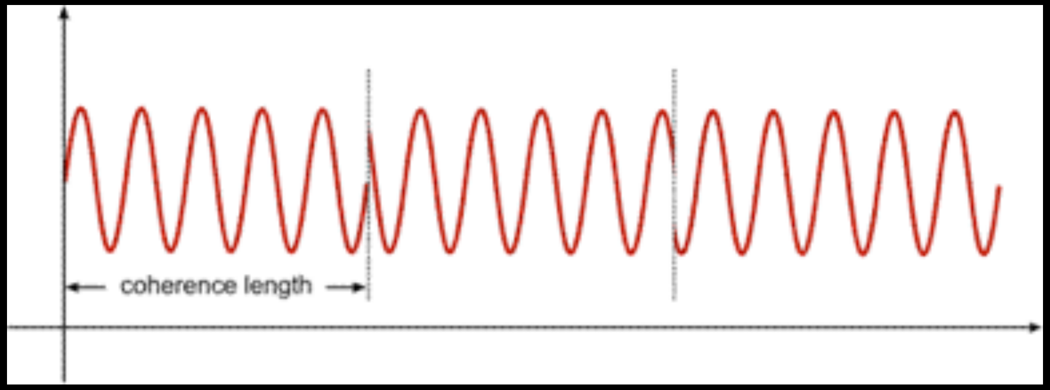


If phase between waves changes, wave sum changes

➔ incoherent



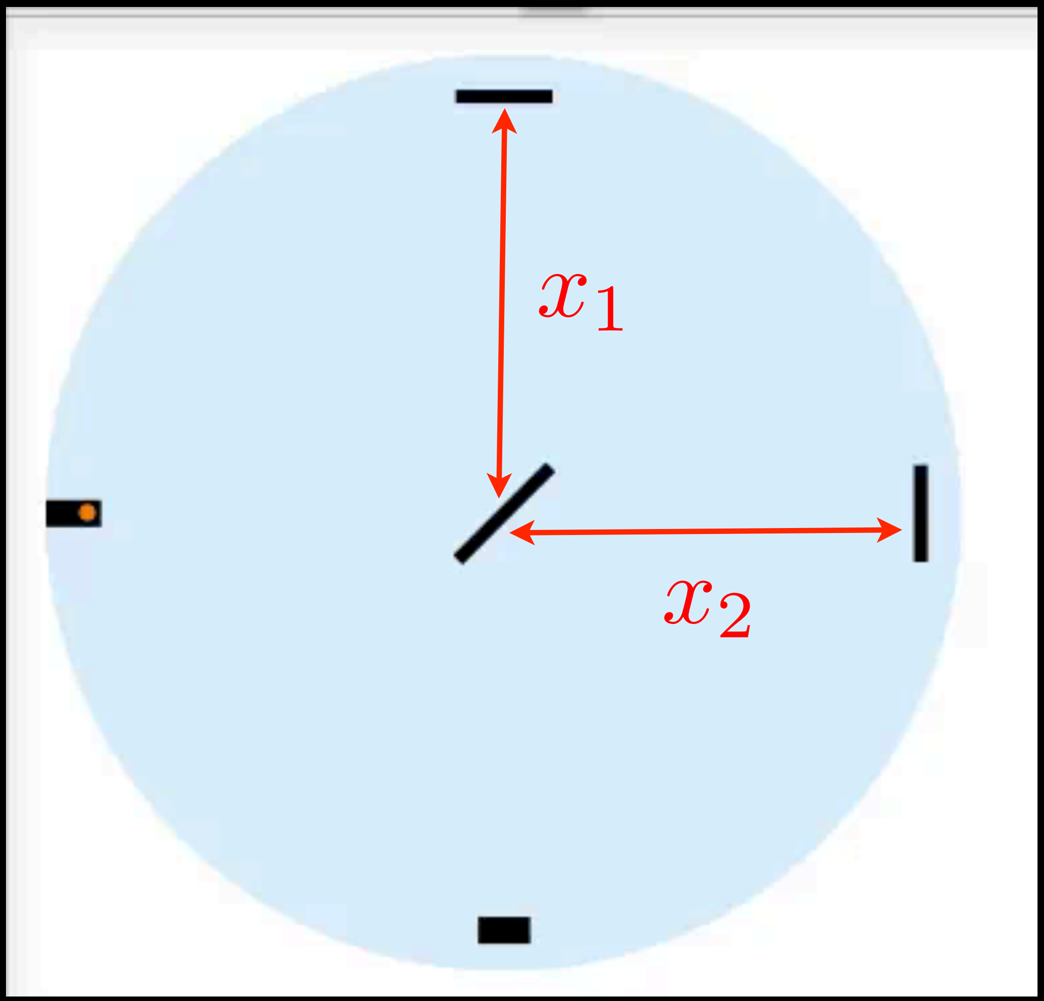
Coherent waves



Length where the wave phase is constant: coherence length

Lasers: long coherence length

Destructive and constructive



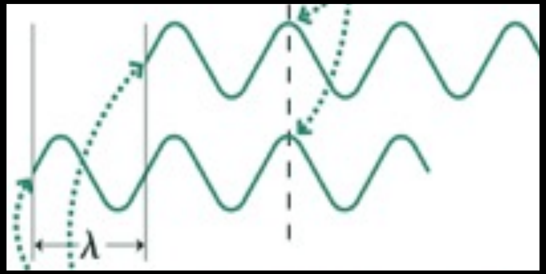
Even for lasers, hard to keep coherence

Split a single light source

Light travels different paths

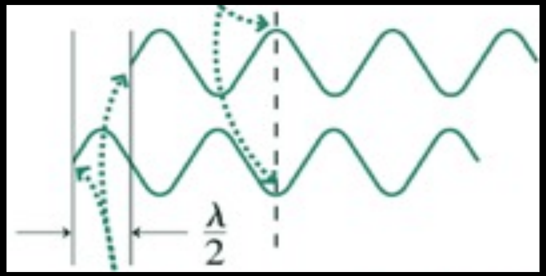
Recombine

If $x_1 = (m\lambda)x_2$, constructive interference.

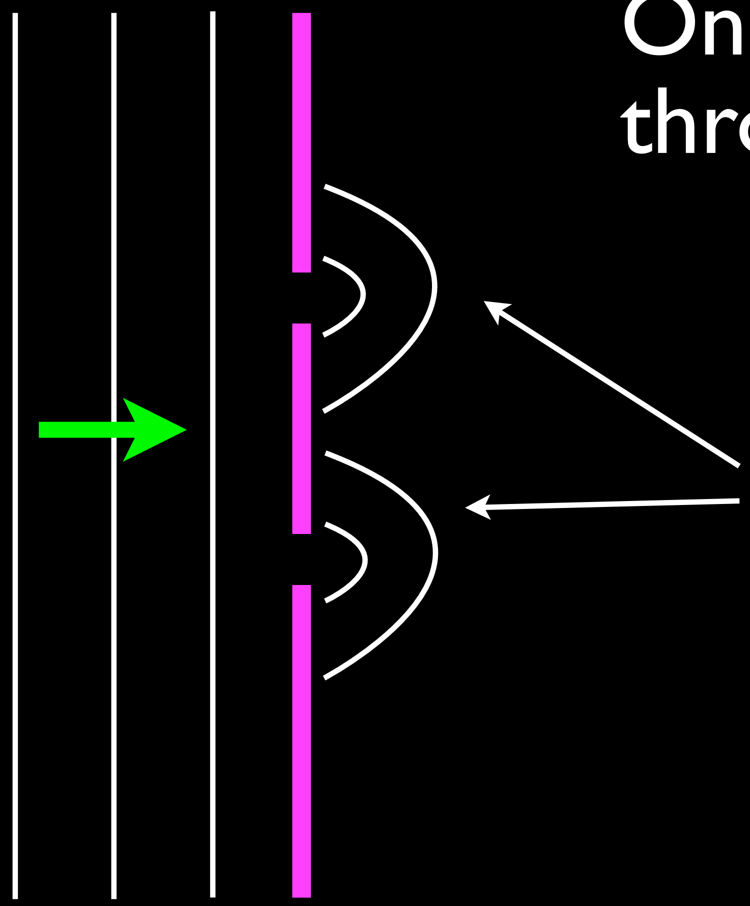


If $x_1 = \left(m + \frac{1}{2}\right)\lambda x_2$,

destructive interference patterns.



Double-Slit interference

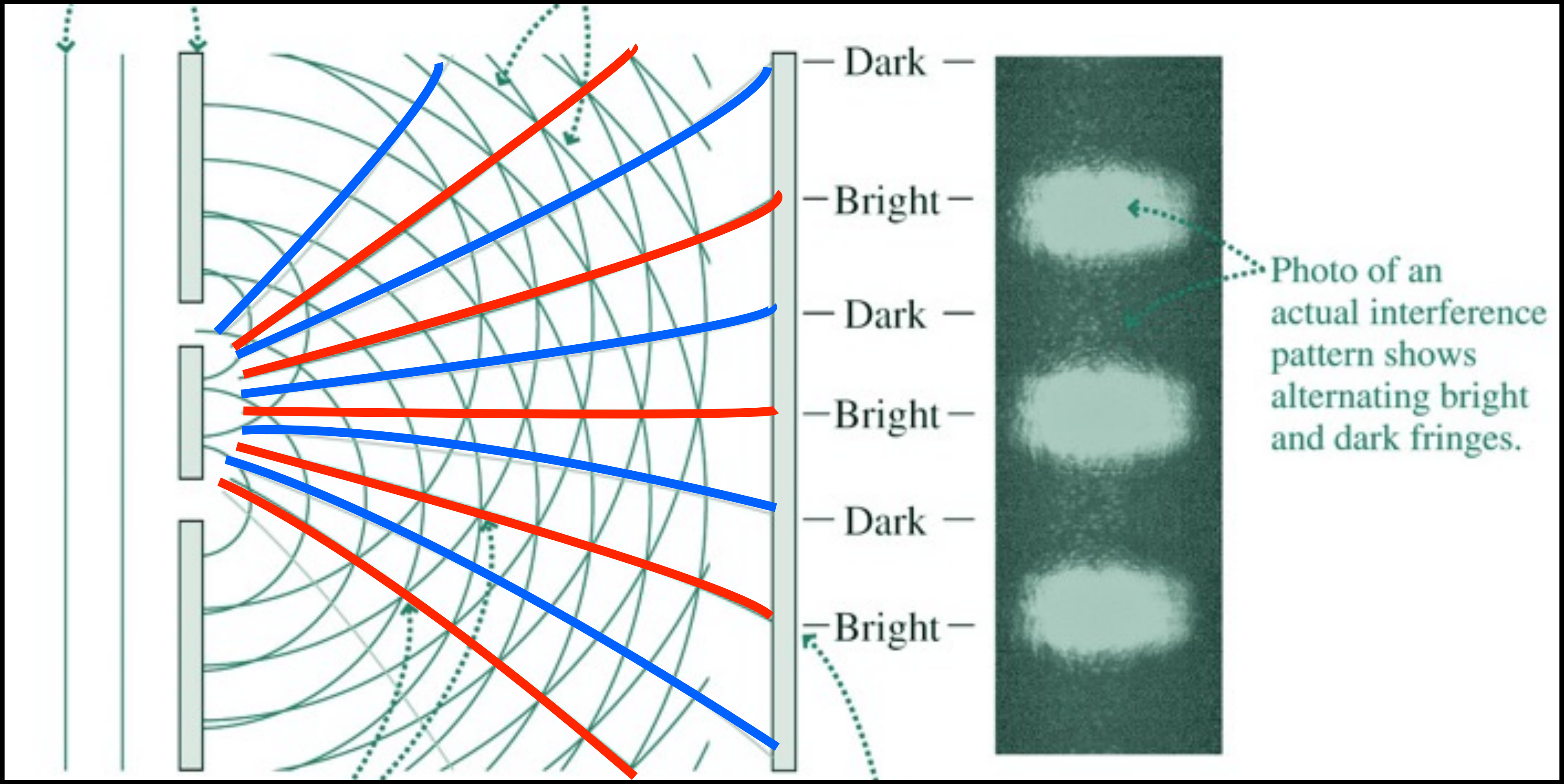


One method of splitting a source is to pass through two narrow slits.

Produces 2 coherent sources.

cylindrical wavefronts interfere

Double-Slit interference



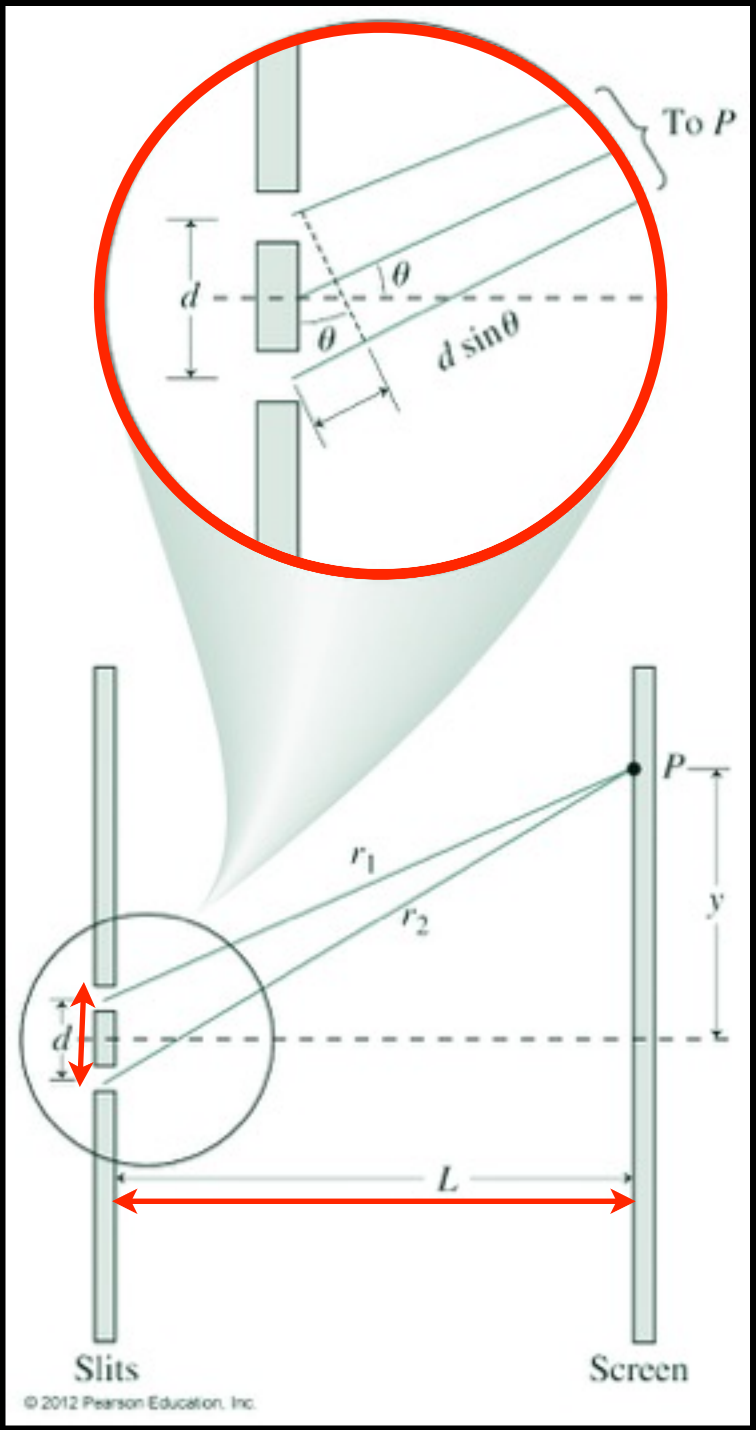
illuminating screen

Constructive interference → bright on screen

Destructive interference → dark on screen

interference fringes

Double-Slit interference



Constructive interference

Difference in path: $m\lambda$

If $L > d$, rays ~ parallel

Difference in path: $d\sin\theta$

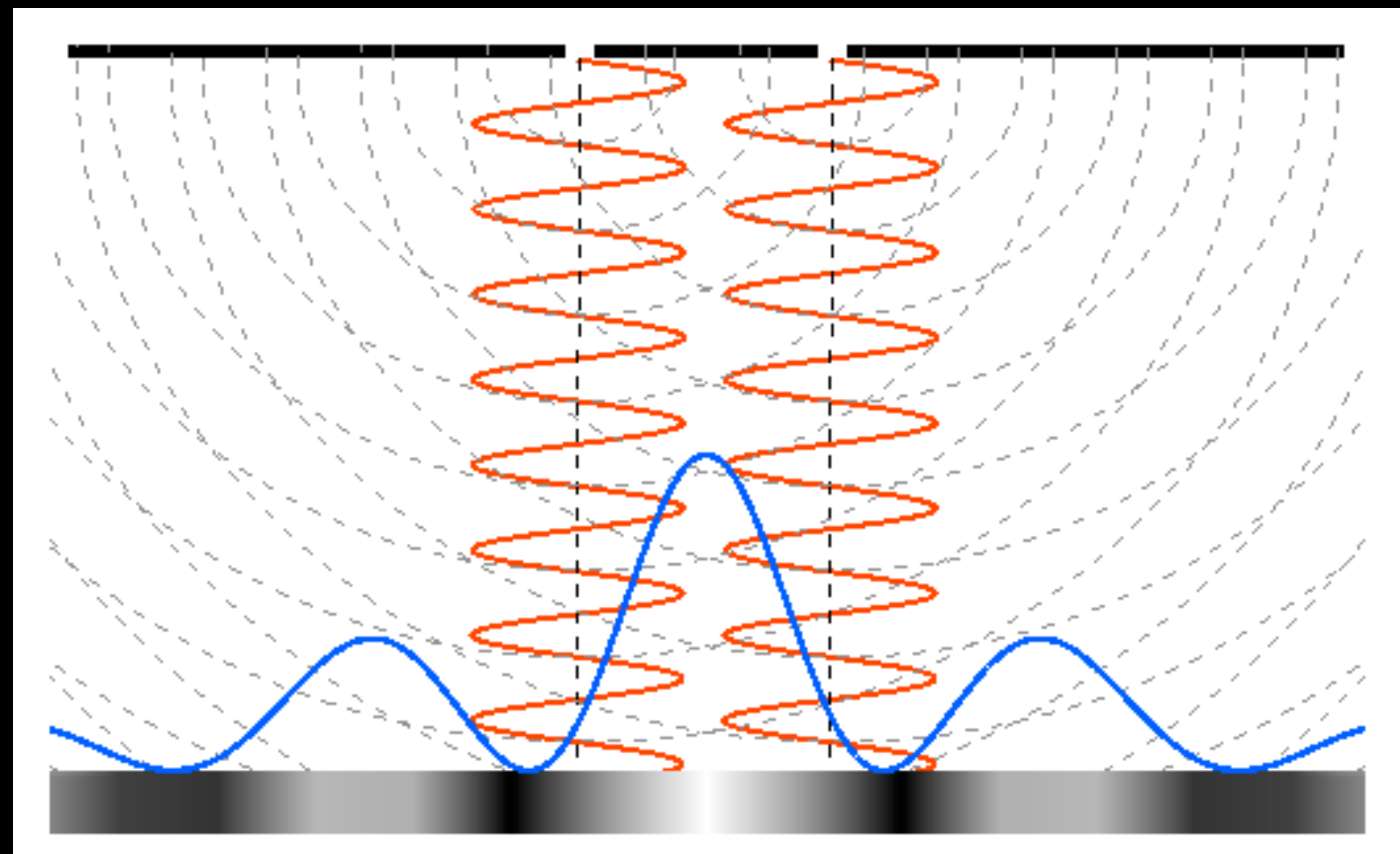
Bright fringes (constructive interference):

$$d\sin\theta = m\lambda$$

$$m = 0, 1, 2, \ldots$$

fringe order

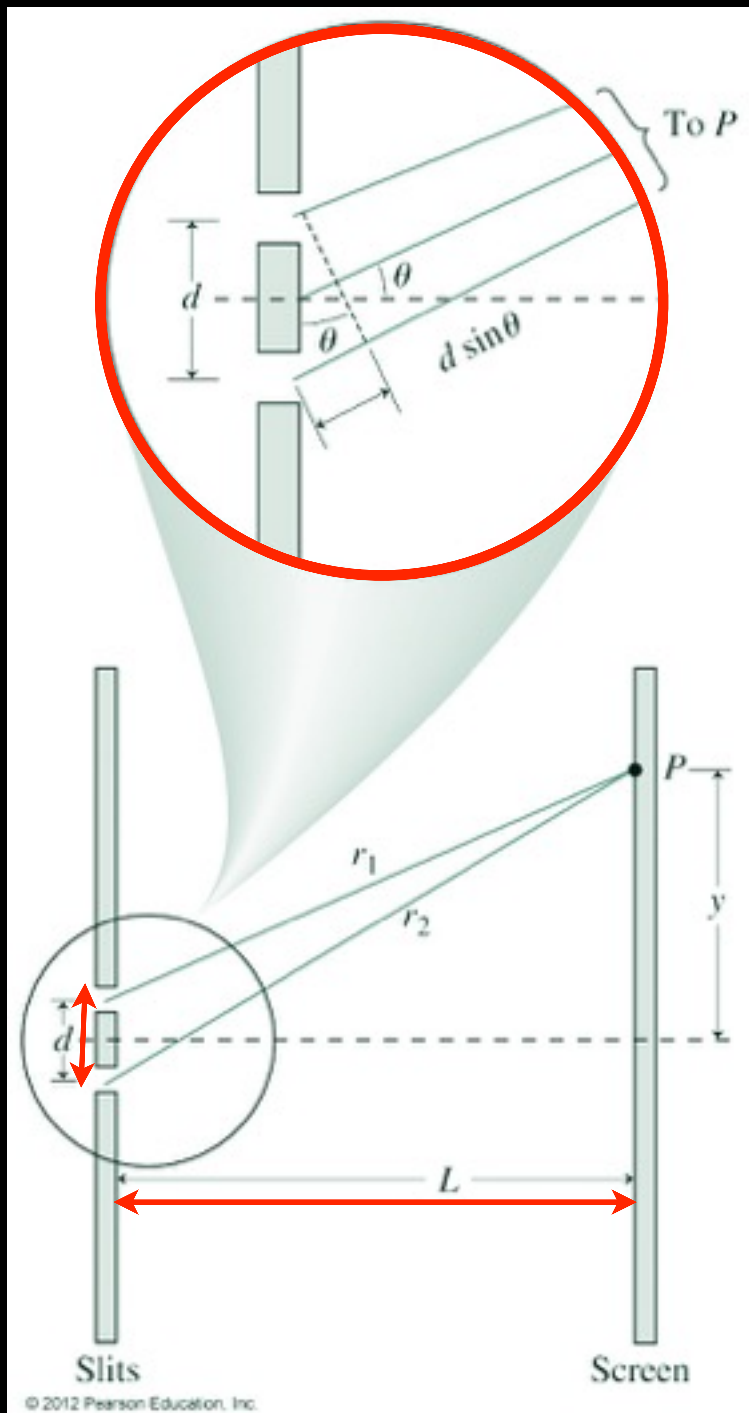
Double-Slit interference



$m = 1 \quad m = 0 \quad m = 1$

Bright fringes

Double-Slit interference



Destructive interference

Difference in path: $\left(m+\frac{1}{2}\right)\lambda$

dark fringes:

$$d\sin\theta=\left(m+\frac{1}{2}\right)\lambda \qquad m=0,1,2,\ldots$$

Typically $L\sim 1\mathrm{m},\ d<1\mathrm{mm}$ and $\lambda<1\mu\mathrm{m}$

Therefore: $\sin\theta\simeq\tan\theta=\frac{y}{L}$

$$y_{\mathrm{bright}}=m\frac{\lambda L}{d} \qquad y_{\mathrm{dark}}=\left(m+\frac{1}{2}\right)\frac{\lambda L}{d}$$

Double-Slit interference

Constructive interference of 2 coherent waves will occur if their path difference is...

(A) λ

(B) $\frac{3\lambda}{2}$

(C) $\frac{5\lambda}{2}$

(D) $\frac{\lambda}{2}$

Double-Slit interference

Example

2 slits 0.075 mm apart are located 1.5 m from a screen.

The 3rd-order bright fringe is 3.8 cm from the screen centre.

What is λ ?

$m = 3$

Use: $y_{\text{bright}} = m\dfrac{\lambda L}{d}$ ➡ $\lambda = \dfrac{y_{\text{bright}} d}{mL}$

$$= \frac{(0.038\text{m})(0.075 \times 10^{-3}\text{m})}{(3)(1.5\text{m})}$$

$$= 633\text{nm}$$

Double-Slit interference

Quiz

If you increase the slit separation in a 2 slit system, how does the spacing of the interference fringes change?

(A) They become further apart

(B) The spacing does not change

(C) They become closer together

$$y_{\text{bright}} = m\frac{\lambda L}{d} \qquad y_{\text{dark}} = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d}$$

Double-Slit interference

A double-slit experiment has a slit spacing 0.12 mm.

If the bright fringes are 5 mm apart when the slits are illuminated with 633-nm wavelength laser light....

What is the slit-to-screen distance, L?

(A) 0.95cm

(B) 95cm

(C) 150cm

(D) 15cm

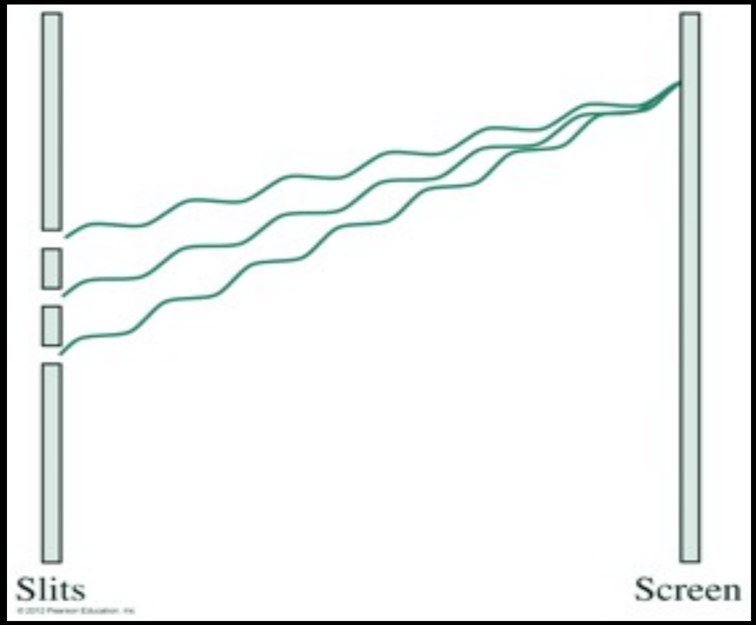
Use: $$y_{\text{bright}} = m\frac{\lambda L}{d}$$

$$\Delta y = 1\frac{\lambda L}{d} - 0\frac{\lambda L}{d} = 5\text{mm}$$

$$L = \frac{\Delta y d}{\lambda} = \frac{(0.12\text{mm})(5.0\text{mm})}{633\text{nm}} = 95\text{cm}$$

Multiple-Slit interference

What if we add more slits?



Constructive interference

All 3 waves must be in phase

Difference in paths: $m\lambda$

For evenly spaced slits: $d\sin\theta = m\lambda$

(same as for 2 slits)

Destructive interference ... more complicated

All waves must add to zero.

For 3 waves, each wave must out of phase with by 1/3.

$$d\sin\theta = \begin{cases} \left(m + \frac{1}{3}\right)\lambda \\ \left(m + \frac{2}{3}\right)\lambda \end{cases}$$

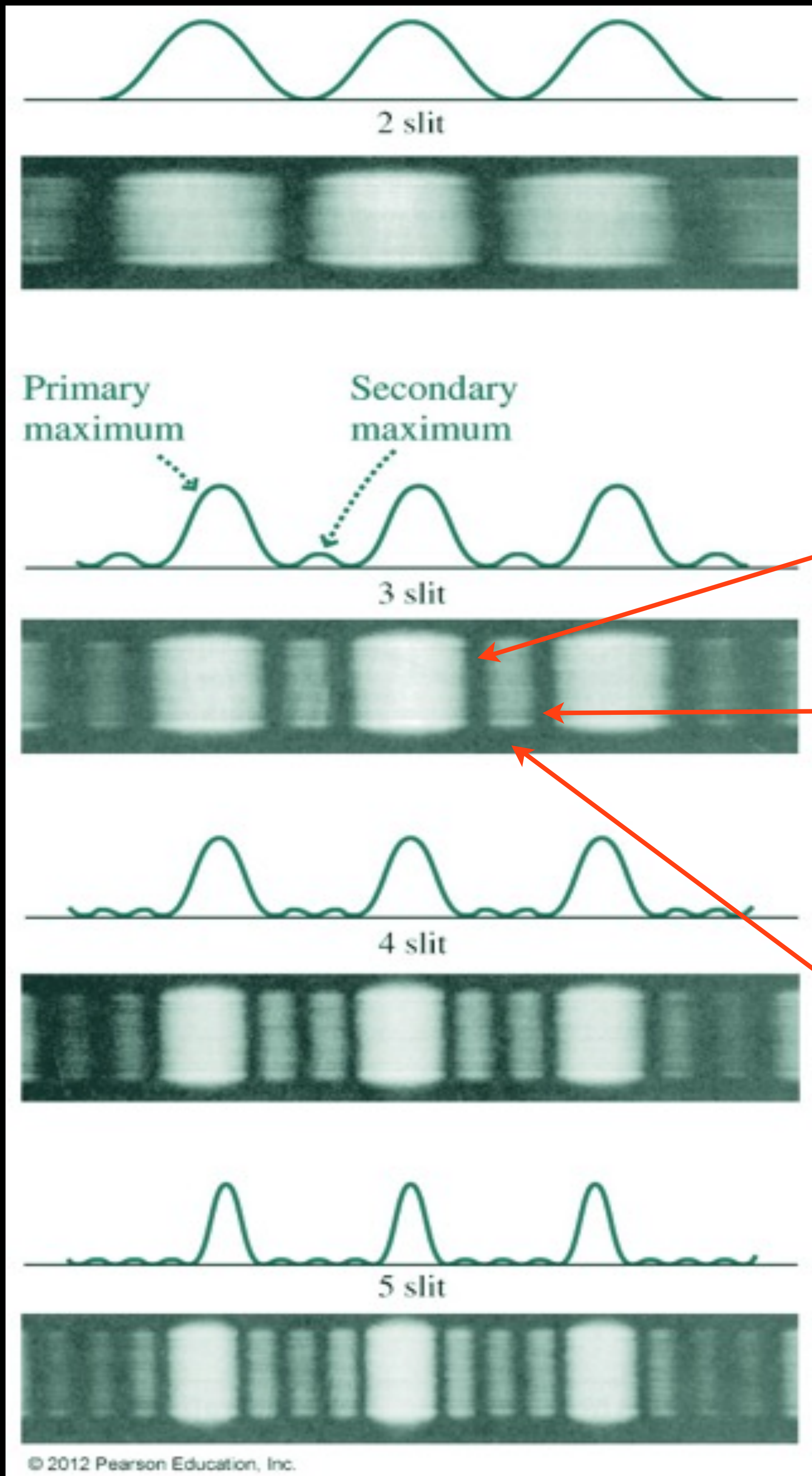
general

$$d\sin\theta = \frac{m}{N}\lambda$$

slit no. (→ N)

m is integer but not integer multiple of N

Multiple-Slit interference



$$\left(m + \frac{1}{3}\right)\lambda$$

$$\left(m + \frac{2}{3}\right)\lambda$$

2 minima between primary maxima $m\lambda$ and $(m+1)\lambda$

secondary maxima

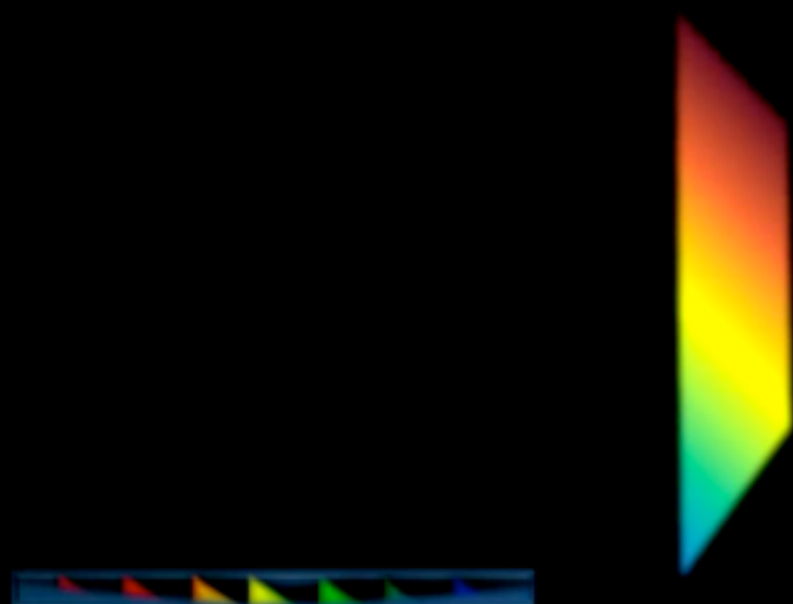
not fully constructive or

fully destructive interference.

Diffraction grating

What if we add *even* more slits?

Diffraction grating: ~1000s slits / cm



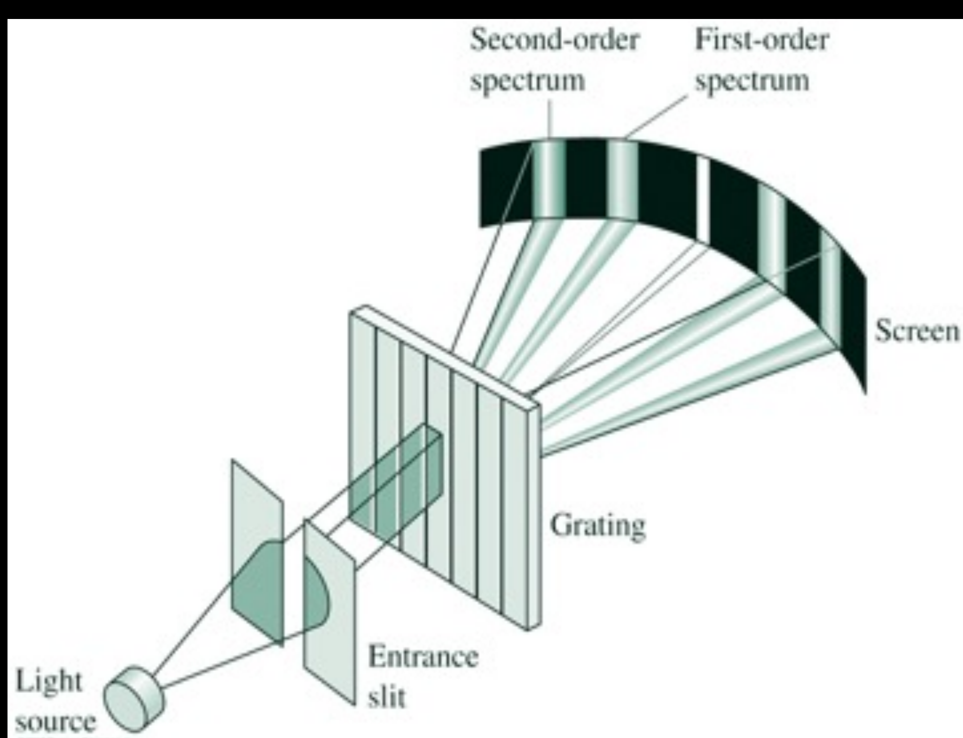
If using multi-wavelength light:

since: $d \sin\theta = m\lambda$

for $m > 0$, angular position θ depends on λ

↓

maxima occur in different places for different wavelengths



Many slits gives very precise locations for the wavelengths (clear separations)

Diffraction grating

Example

Light from glowing Hydrogen contains $H\alpha$ (hydrogen-alpha) 656.3nm and $H\beta$ (hydrogen-beta) 486.1 nm.

Find the 1st order angular separation between these wavelengths when using a grating of 6000 slits /cm.

$$m = 1$$

6000 slits / cm ➡ $d = \frac{1}{6000}\text{cm} = 1.667\mu\text{m}$

$$\theta_\alpha = \sin^{-1}\left(\frac{\lambda}{d}\right) = \sin^{-1}\left(\frac{0.6563\mu\text{m}}{1.667\mu\text{m}}\right) = 23.2^\circ$$

$$\theta_\beta = \sin^{-1}\left(\frac{\lambda}{d}\right) = \sin^{-1}\left(\frac{0.4861\mu\text{m}}{1.667\mu\text{m}}\right) = 17^\circ$$

$$\Delta\theta = 6.2^\circ$$

Diffraction grating

Quiz

Green light at 520 nm is diffracted by a grating with 3000 lines / cm.

Through what angle is the light diffracted in 5th order?

(A) 0.07°

(B) 9.0°

(C) 51°

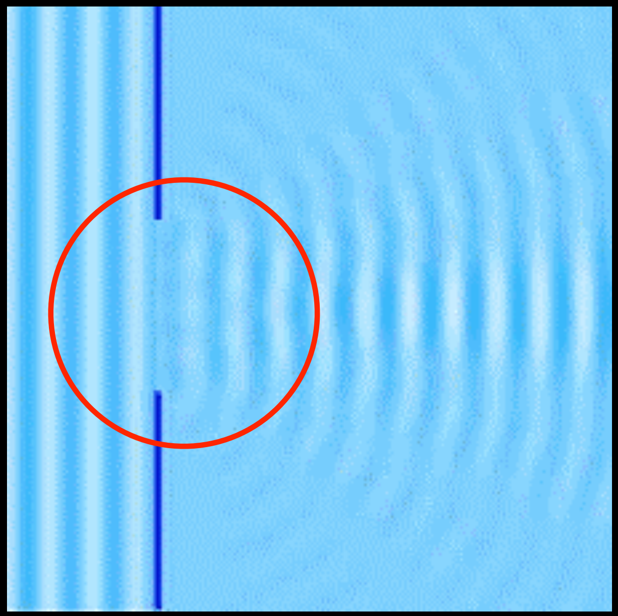
(D) 0.05°

maxima at: $\theta = \sin^{-1}\left(\frac{m\lambda}{d}\right)$

$$d = \frac{1}{3000\text{cm}^{-1}} = 3.33\mu\text{m}$$

$$\theta = \sin^{-1}\left(\frac{5 \times 520\text{nm}}{3.33\mu\text{m}}\right) = 51^\circ$$

Diffraction

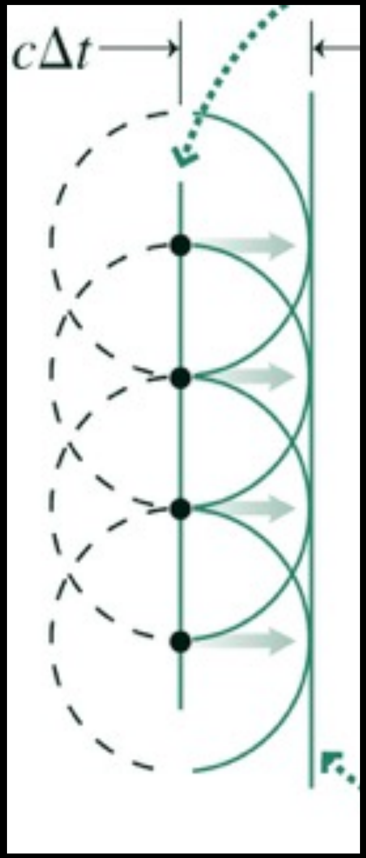


Why does the slit cause cylindrical waves?

⬇ light bending as it passes object

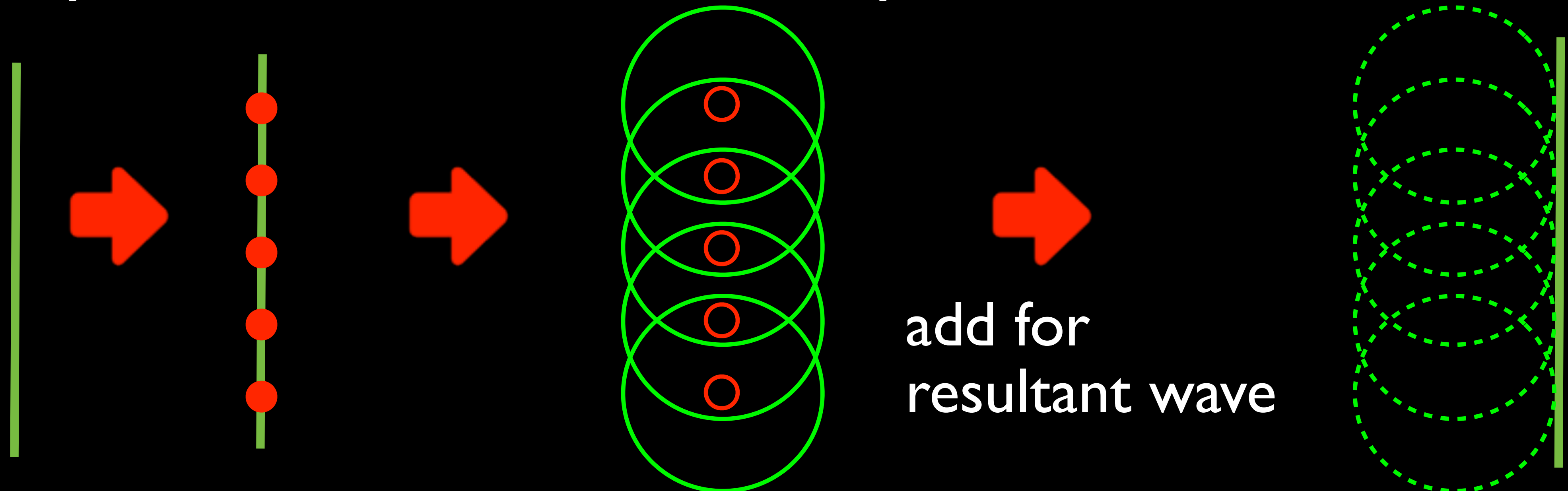
Diffraction

Really need Maxwell's equations but....



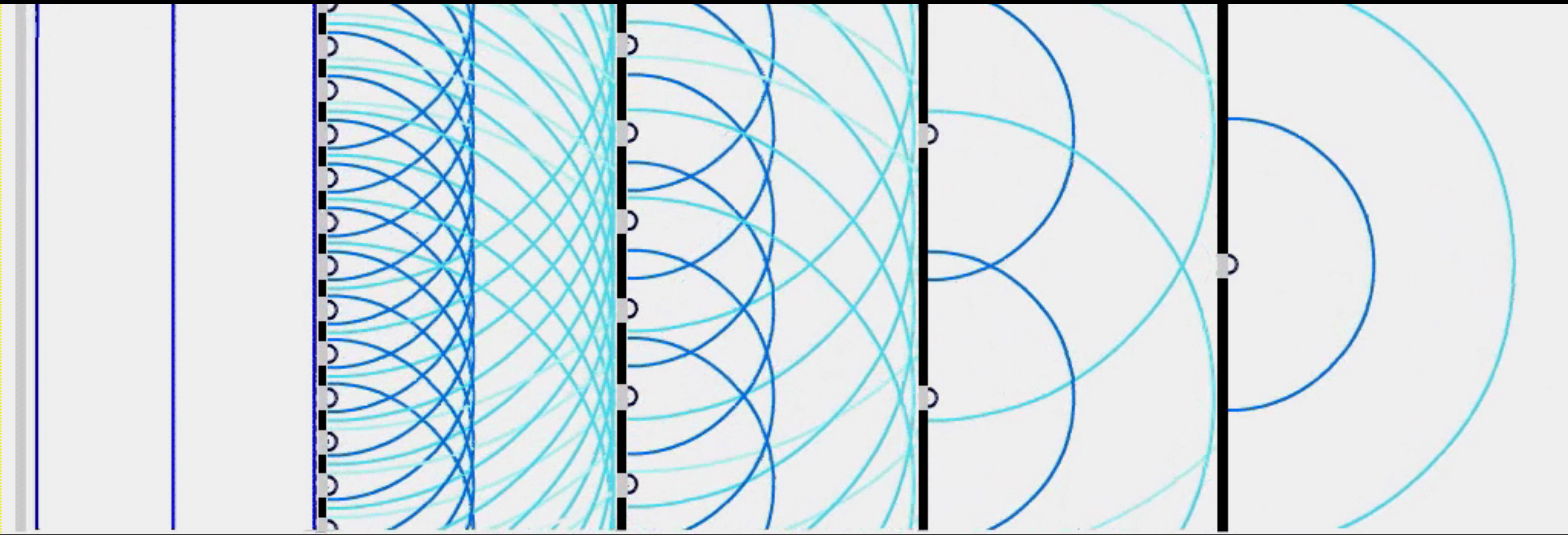
Huygens' Principal: (pronounce: her-genz)

All points on wave front are spherical wave sources.



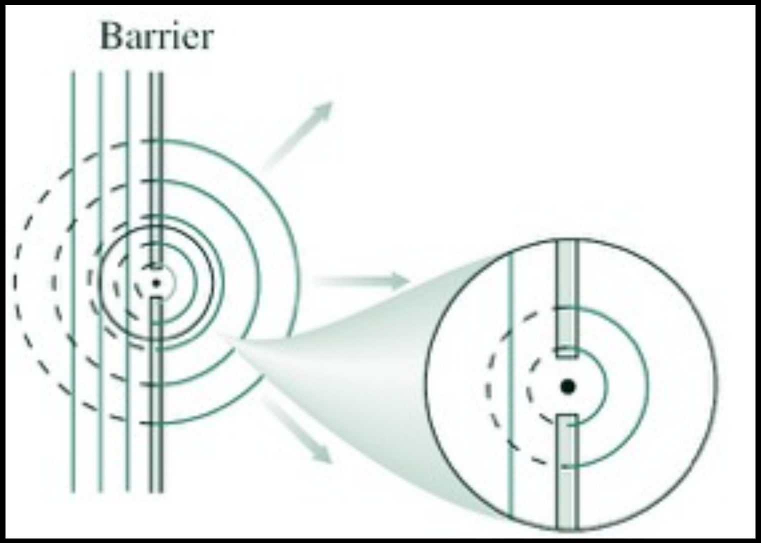
Diffraction

Spherical waves blocked by the barrier; only some pass through slit.



Sum of the remaining spherical waves ➡ wave bends (diffraction)

Diffraction



If the slit width ~ wavelength

↓

slit = single wave source

But....

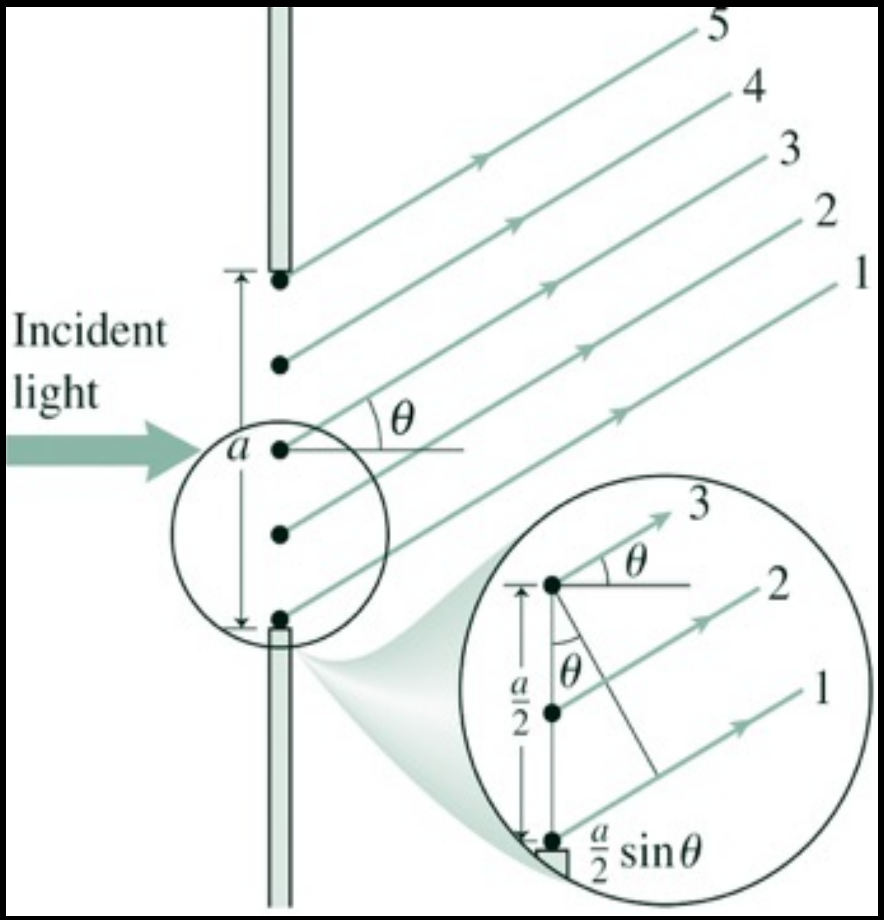
If slit width is *larger*

↓

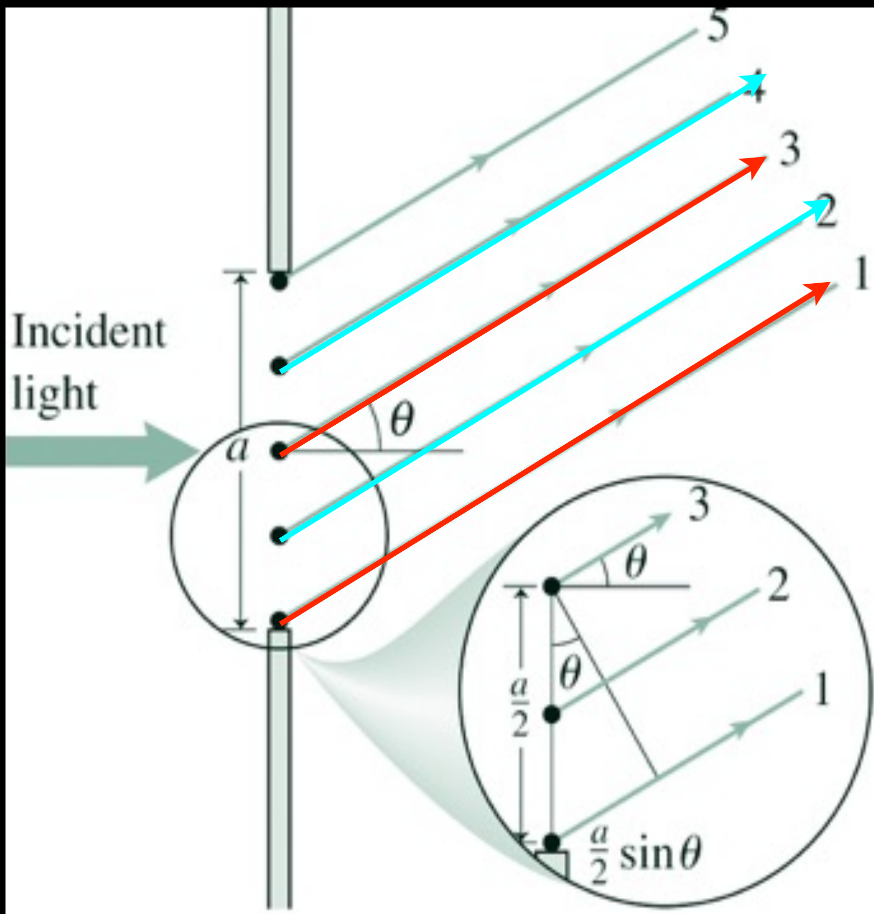
Each point in slit is a wave source

↓

Interference between waves in slit



Diffraction



Consider 5 equal spaced sources:

Path length for ray 1 and 3 differ by $\frac{1}{2}a\sin\theta$

Destructive interference if

$$\frac{1}{2}a\sin\theta = \frac{1}{2}\lambda$$

or

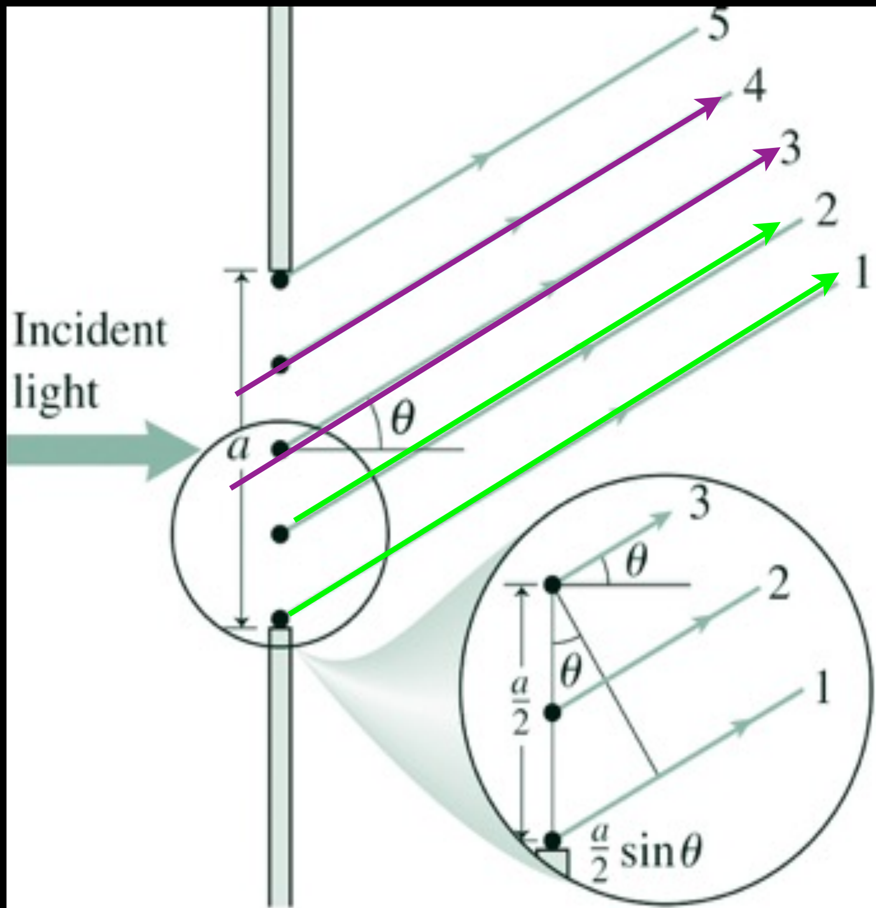
$$a\sin\theta = \lambda$$

But if ray 1 and 3 interfere destructively, so do 2 and 4...

All rays in lower half of slit will interfere destructively with ray $\frac{a}{2}$ above it.

If you look at the slit at θ such that $a\sin\theta = \lambda$, you will see no light

Diffraction



Similarly

Ray I and 2 differ by $\frac{1}{4}a\sin\theta$

Destructive interference if

$$\frac{1}{4}a\sin\theta = \frac{1}{2}\lambda$$

or

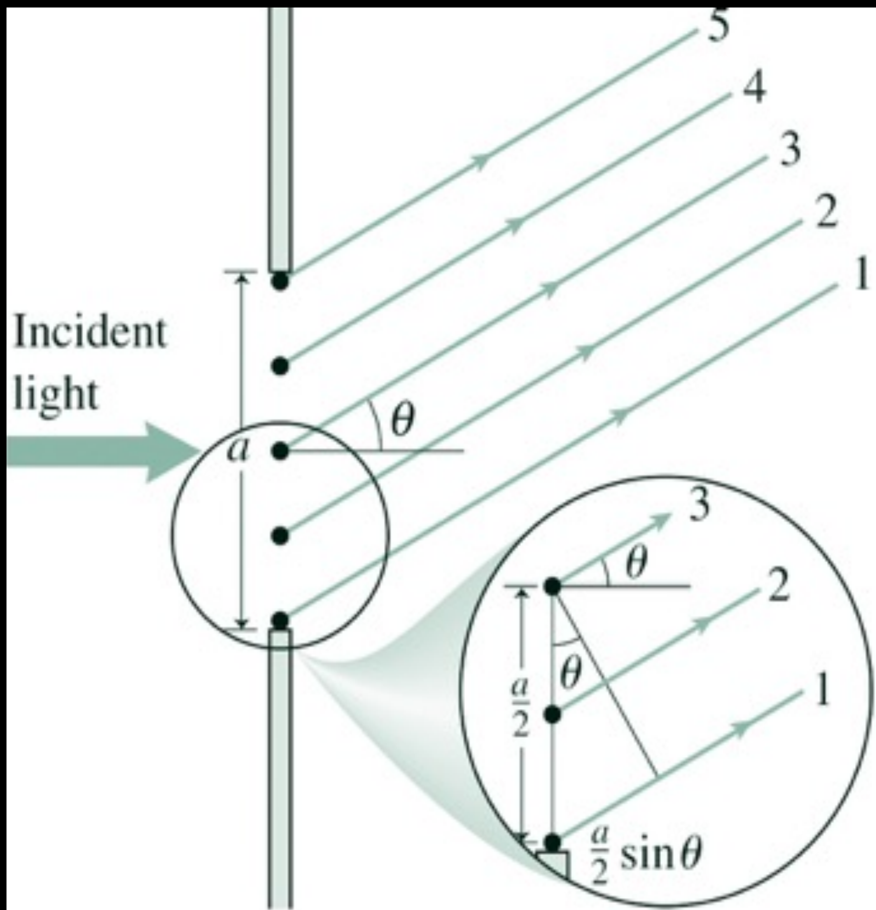
$$a\sin\theta = 2\lambda$$

But is ray I and 2 interfere destructively, so do 3 and 4...

All rays in lower 3/4 of slit will interfere destructively with ray $\frac{a}{4}$ above it.

If you look at the slit at θ such that $a\sin\theta = 2\lambda$, you will see no light

Diffraction



Generally:

(divide slit into 6, 7, 8 etc sources)

$$a \sin\theta = m\lambda$$

Destructive interference, single-slit diffraction

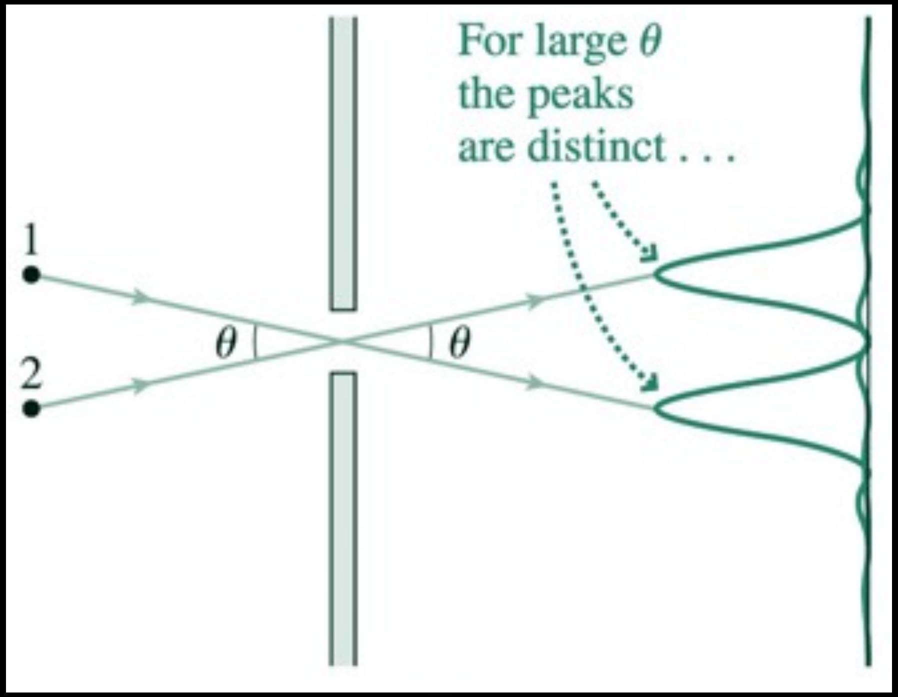
for $m = 1, 2, 3, ...$

for $m = 0$ no destructive interference at the central maximum.

Diffraction Limit

Diffraction creates a limit for how close two object can be....

... and still be resolved.

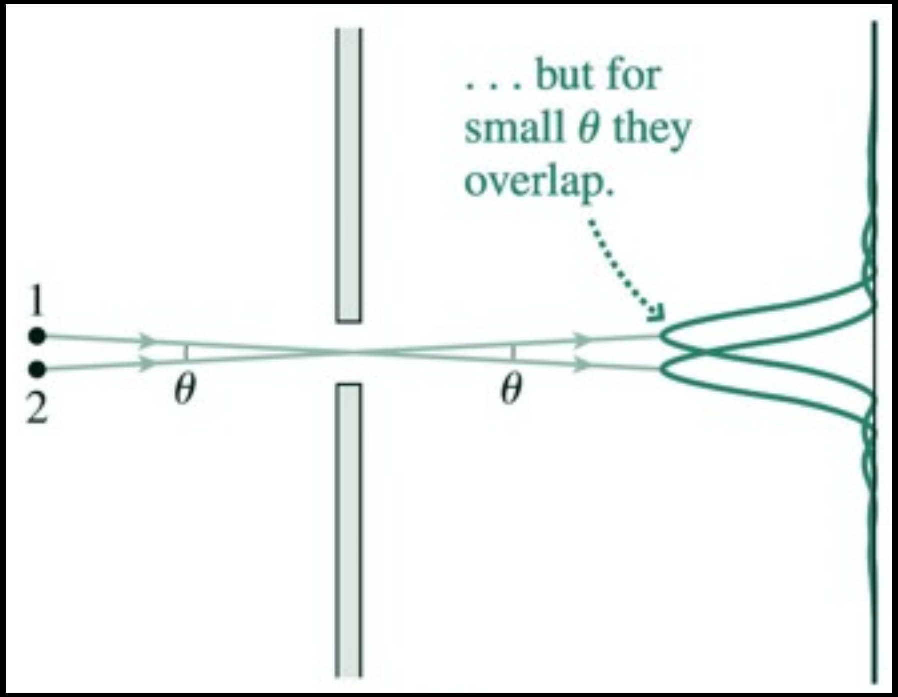


2 sources illuminate the slit

Their waves reach the slit at different angles

(assume sources are incoherent, no regular interference pattern)

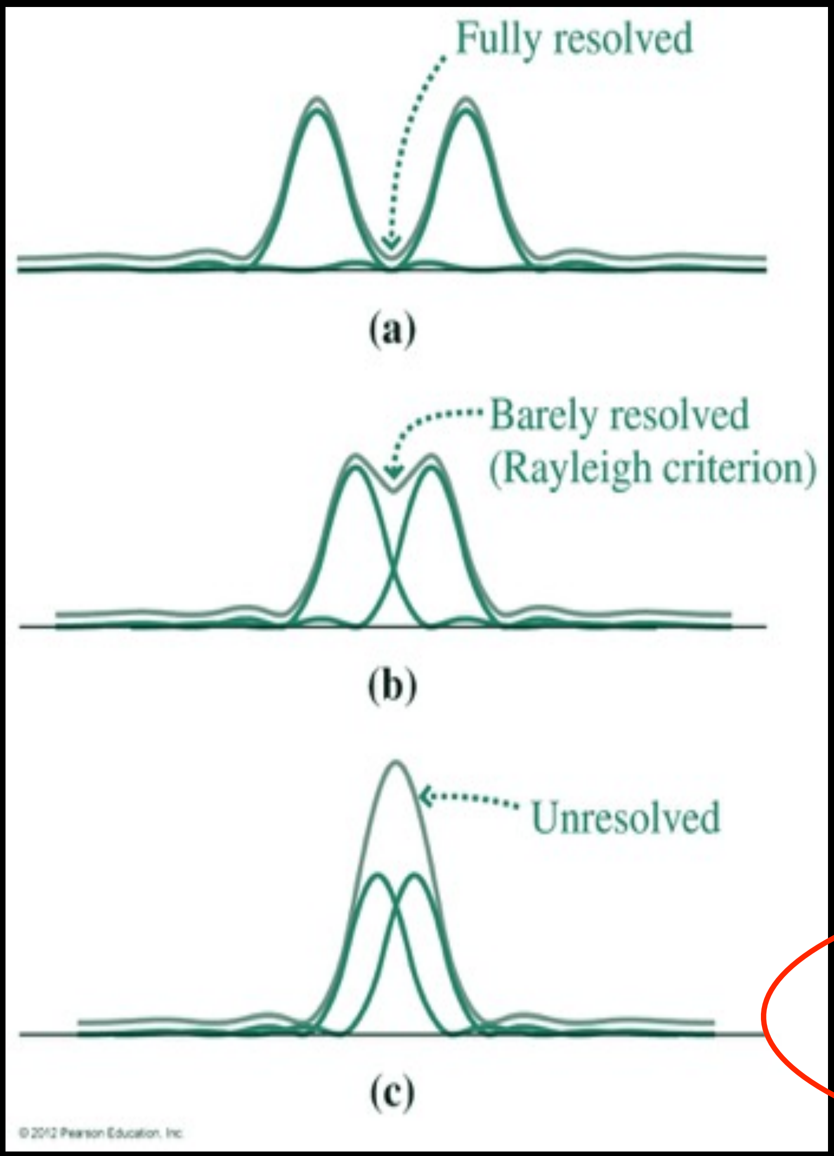
2 single slit diffraction patterns



As the sources get closer

Central maxima begins to overlap

Diffraction Limit



Diffraction patterns merge

2 peak structure disappears

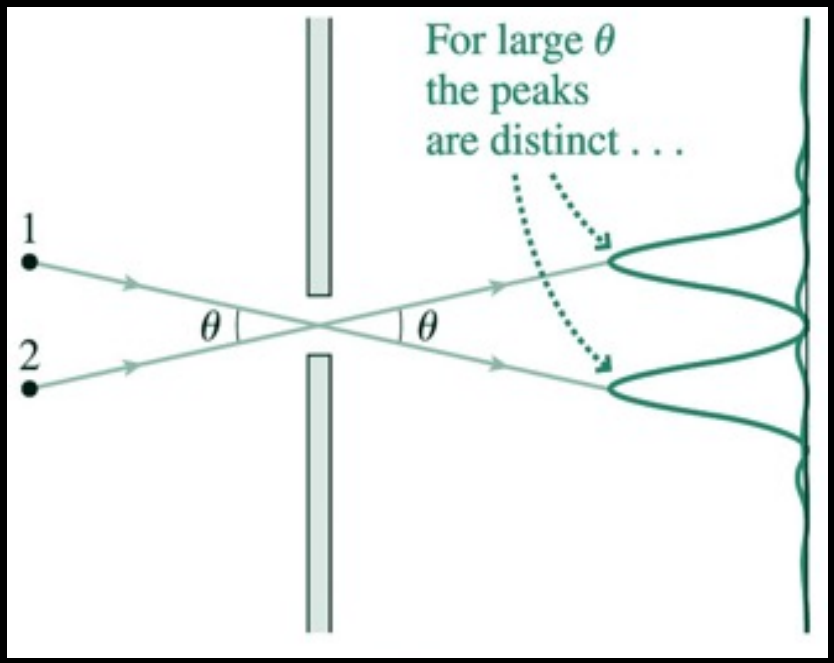
2 peak visible if

Central *maxima* of peak 1 = 1st *minima* of peak 2

Rayleigh criterion

when true, 2 sources are *just resolved*

Diffraction Limit



The angular separation, θ , between the peaks

=

The angular separation, θ , between the sources

1st minima: $\sin\theta = \dfrac{\lambda}{a}$

since $\lambda << a$ ➡ small angle approximation: $\sin\theta \simeq \theta$

➡ $\theta_{\min} = \dfrac{\lambda}{a}$ (Rayleigh criterion, slit)

If using a circular aperture, not slit (e.g. a camera):

➡ $\theta_{\min} = \dfrac{1.22\lambda}{D}$ (Rayleigh criterion, circular aperture)

D ← aperture diameter

Diffraction Limit

Example

An astroid $20 \times 10^6 \mathrm{km}$ away appears on a collision course with the Earth!

What is the minimum size for the astroid that could be resolved with the 2.4 m diameter diffraction-limited Hubble Space Telescope?

diffraction is what prevents the resolved imaged

(not atmosphere .... etc)

circular aperture

Diffraction Limit

Example

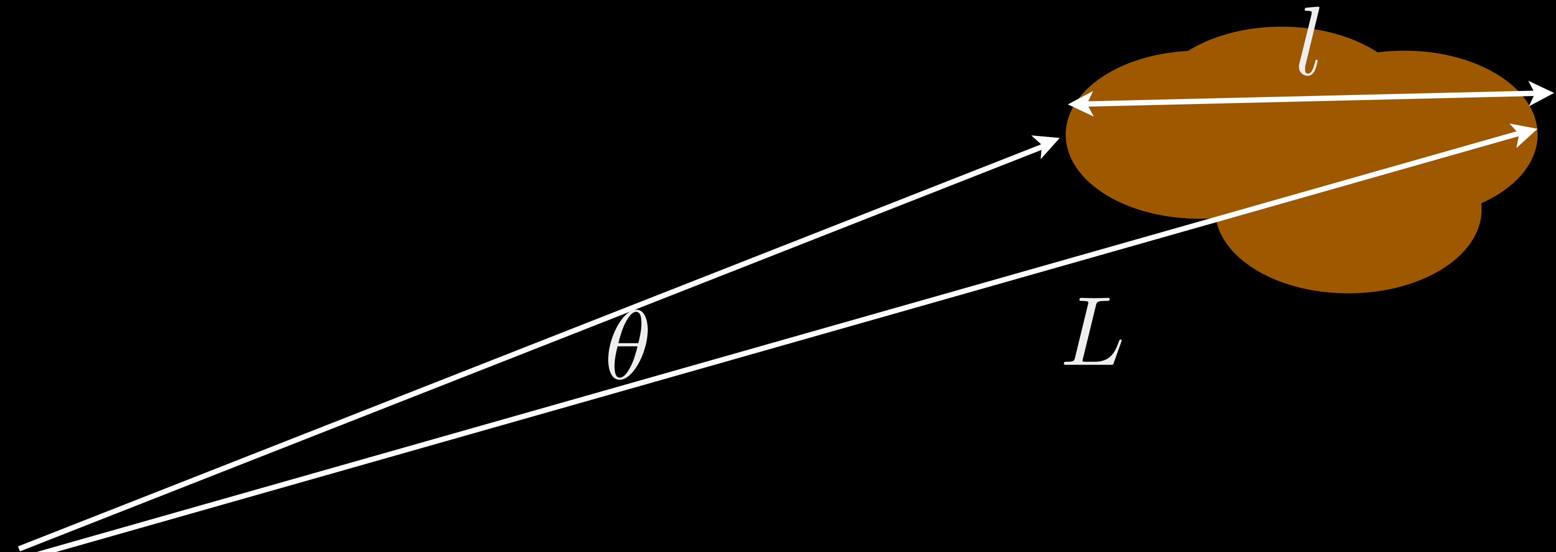
An astroid $20 \times 10^6 \text{km}$ away appears on a collision course with the Earth!

What is the minimum size for the astroid that could be resolved with the 2.4 m diameter diffraction-limited Hubble Space Telescope?

$$\theta_{\min} = \frac{1.22\lambda}{D}$$

$$\frac{l}{L} = \frac{1.22\lambda}{D}$$

$$l = \frac{1.22\lambda L}{D} = 5.6\text{km}$$



Opposite ends of the asteroid = 2 peaks

$\theta \simeq \frac{l}{L}$ (small angle approximation)

Diffraction Limit

Example

An astroid $20 \times 10^6 \text{km}$ away appears on a collision course with the Earth!

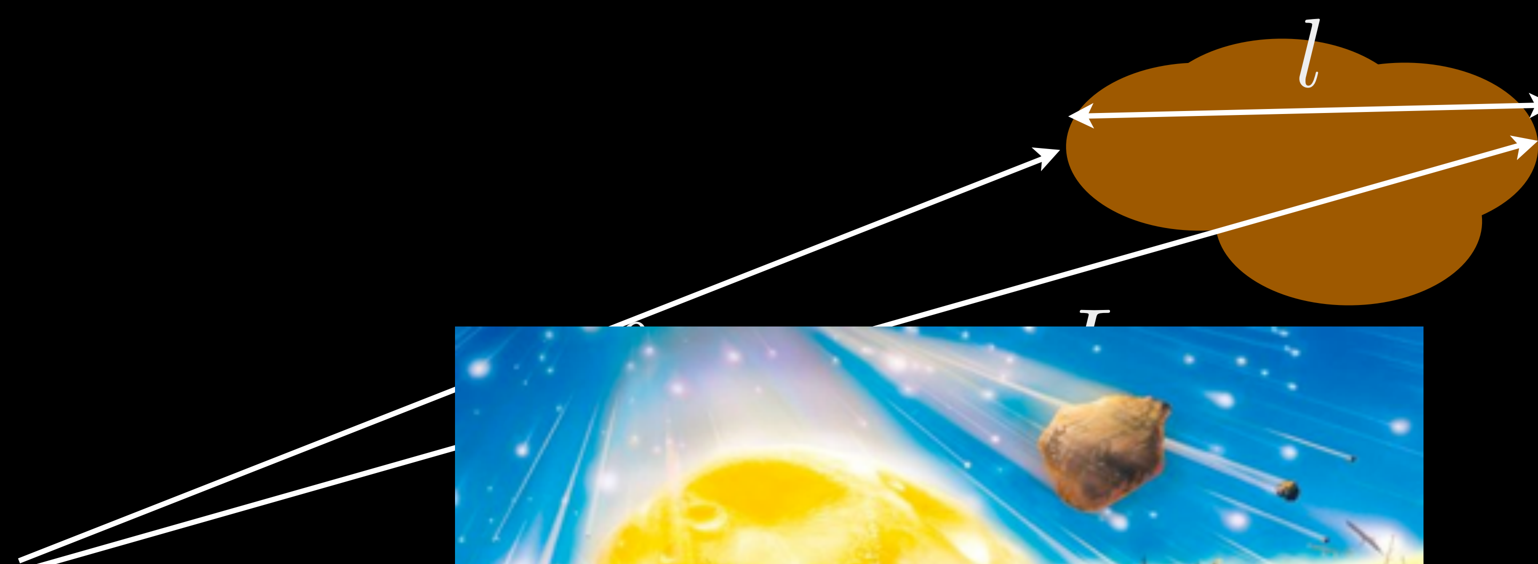
What is the minimum size for the astroid that could be resolved with the 2.4 m diameter diffraction-limited Hubble Space Telescope?

$$\theta_{\min} = \frac{1.22\lambda}{D}$$

$$\frac{l}{L} = \frac{1.22\lambda}{D}$$

$$l = \frac{1.22\lambda L}{D} = 5.6\text{km}$$

big problem!



Op oid = 2 peaks

θ oximation)

Diffraction Limit

Quiz

What is the longest wavelength you could use to resolve an object with angular diameter 0.44 mrad, using a microscope with aperture 1.2 mm in diameter?

(A) 528nm

(B) 220nm

(C) 130nm

(D) 430nm

$$\theta_{\min} = \frac{1.22\lambda}{D}$$

$$\lambda = \frac{\theta_{\min} D}{1.22} = \frac{(0.44\text{mrad})(1.2\text{mm})}{1.22} = 430\text{nm}$$

Real optics

movie

Real optics

What has been created at the VLBA (Very Large Telescope Array)?

(A) The biggest mirror on a telescope

(B) An artificial star

(C) A new type of laser

(D) A defense shield

Real optics

Quiz

Why is this useful?

(A) The laser reflects of stars to find their distance

(B) We can communicate with extra-terrestrial life

(C) Allows the 'adaptive optics' technique to be used anywhere in the sky.

(D) It tracks communication satellites around the world

Real optics

How big is the mirror on the telescope that the laser is launched from?

(A) 10 m

(B) 8.2 m

(C) 3 m

(D) 5 m

Real optics

What height is the “star” created?

(A) 90 km

(B) 10 km

(C) The same as our nearest star

(D) The same as the moon

Real optics

Quiz

How faint (weak / hard to see) is the artificial star?

(A) 20 x fainter than the faintest star that can be seen with the telescopes

(B) 20 x fainter than the brightest star that can be seen by eye

(C) 20 x fainter than the faintest star that can be seen by eye

(D) 20 x fainter than the brightest star that can be seen by eye

Real optics

What limits a ground-based telescope's image sharpness?

(how good the image is)

(A) Diffraction

(B) Atmospheric turbulence

(C) Moon light

(D) Sun light

Real optics

How does adaptive optics solve this?

(A) It uses a bigger mirror

(B) The laser finds the object's location more accurately

(C) A flexible mirror corrects the image

(D) The laser freezes the image

Real optics

Adaptive optics needs reference star. Why isn't a real star used?

(A) A suitable star isn't always in the sky area you want to observe

(B) A real star's light is too variable (it twinkles)

(C) The reference star must be red

(D) The moon is too bright

Real optics

How does the laser make the star?

(A) Shoots a beam of light into the air

(B) Causes sodium atoms in the atmosphere to glow

(C) The laser reflects of a real star, making it brighter

(D) The laser reflects off the moon

Real optics

Quiz

What do scientists hope to observe with this new technique?

(A) Black holes forming in other galaxies

(B) ‘high redshift’ (young) galaxies

(C) Our galactic centre

(D) All the above