Diffraction

(38.1 – 38.4)

Interference effects for continuous sources:

i) Light bends around corners.
ii) "Shadows" fill in
iii) "Parallel" beams always spread
iv) Resolution of microscopes and telescopes is limited

Practice: Chapter 38,
Objective Questions 4, 5, 6
Conceptual Questions 2, 5, 9, 10
Problems 3, 7, 9, 10

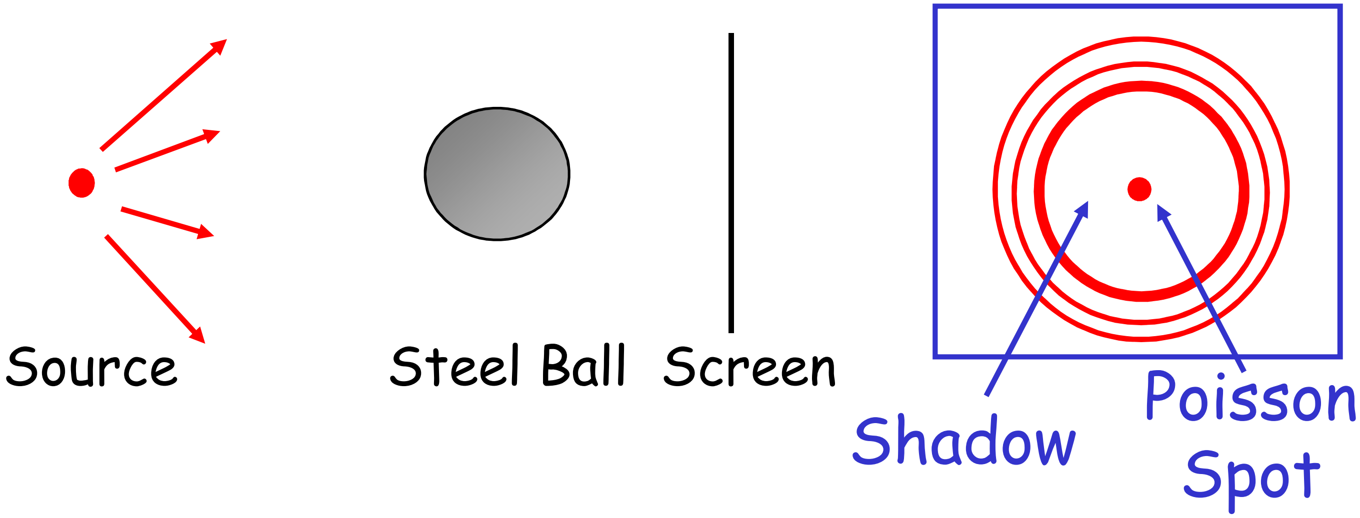
Fraunhofer Diffraction: (easy math)

Source, screen " at ∞"
eg. Laser & narrow slit.

Fresnel Diffraction: (complicated math)

Source distance, object size, screen distance all comparable.

eg.



Source

Steel Ball

Screen

Shadow

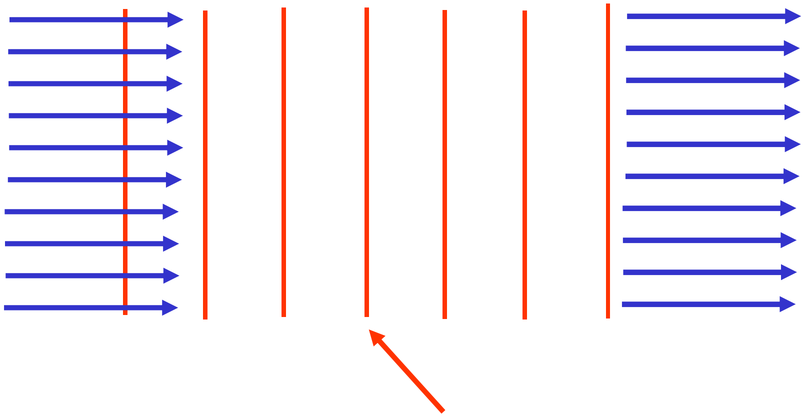
Poisson Spot

Huygens's Principle

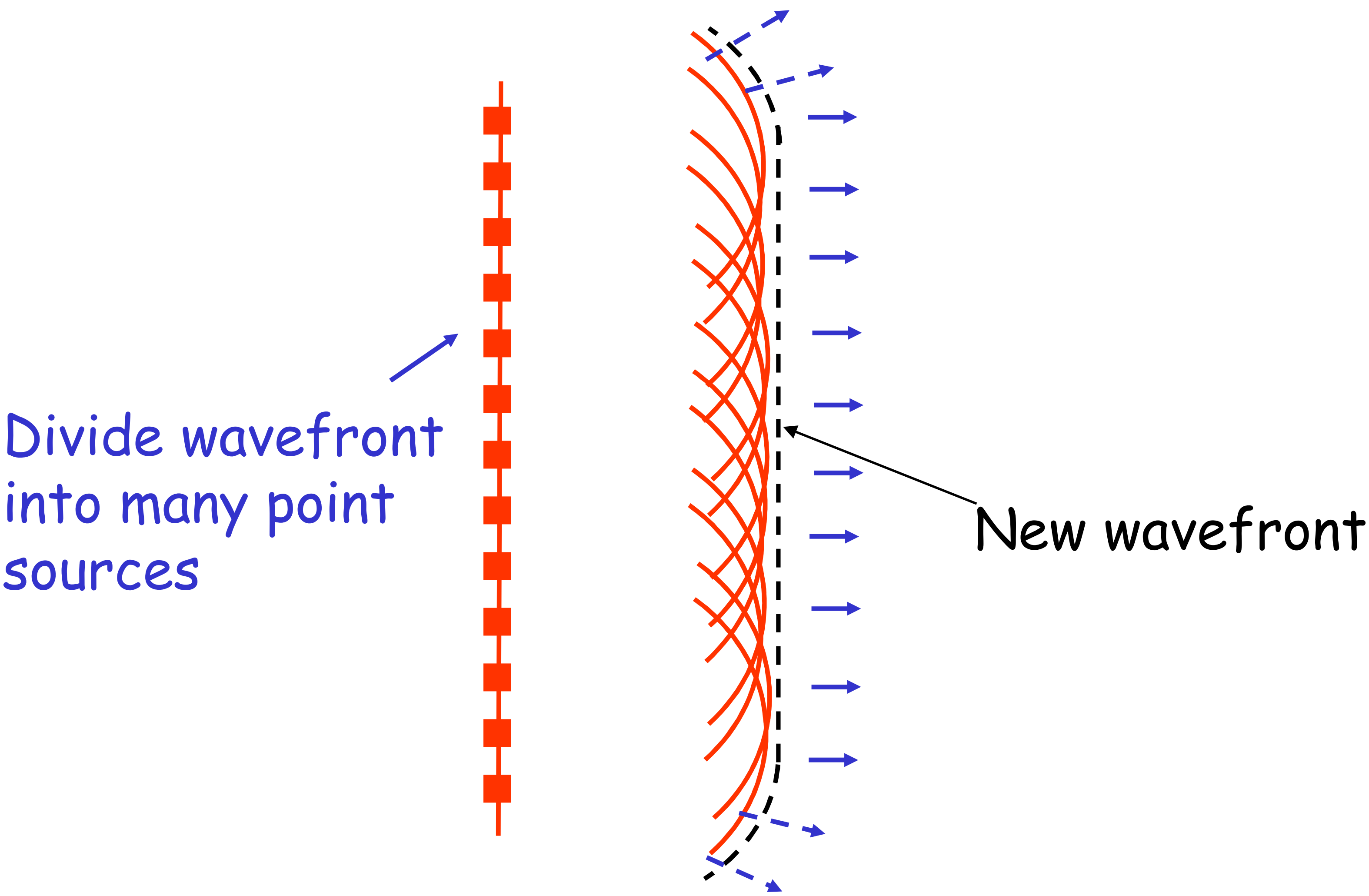
(Christiaan Huygens, ~ 1678)

Wave propagation can be treated as if each point on a wavefront is a source of semicircular "wavelets" spreading out in forward directions. These wavelets overlap and interfere to form the wave at later times.

e.g., parallel beam of light: "Plane wave"

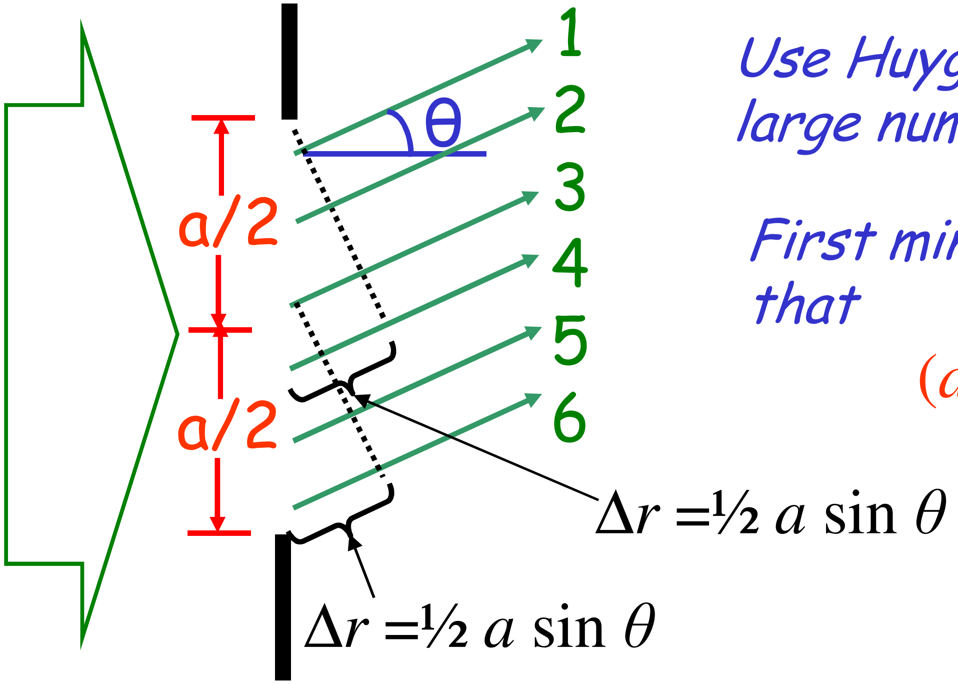


wavefronts: flat *planes* for a parallel beam.



Flat wavefront (parallel rays) gives a <u>new</u> flat wavefront (EXCEPT near the edges).

Single Slit, width = a



Use Huygens's idea: Treat the slit as a large number of point sources.

First minimum: choose θ so that

$$(a/2)\sin\theta = \lambda / 2$$

Add up rays in <u>pairs</u>:

Ray (4) is $\frac{1}{2}$ cycle behind (1) -> Cancel
Ray (5) is $\frac{1}{2}$ cycle behind (2) -> Cancel
Ray (6) is $\frac{1}{2}$ cycle behind (3) -> Cancel

When $\frac{1}{2} a \sin \theta = \frac{1}{2} \lambda$ (*i.e.*, $a \sin \theta = \lambda$), each ray from the top half of the slit interferes destructively with the ray a distance a/2 below; everything cancels, and there is zero total intensity.

Increase θ until

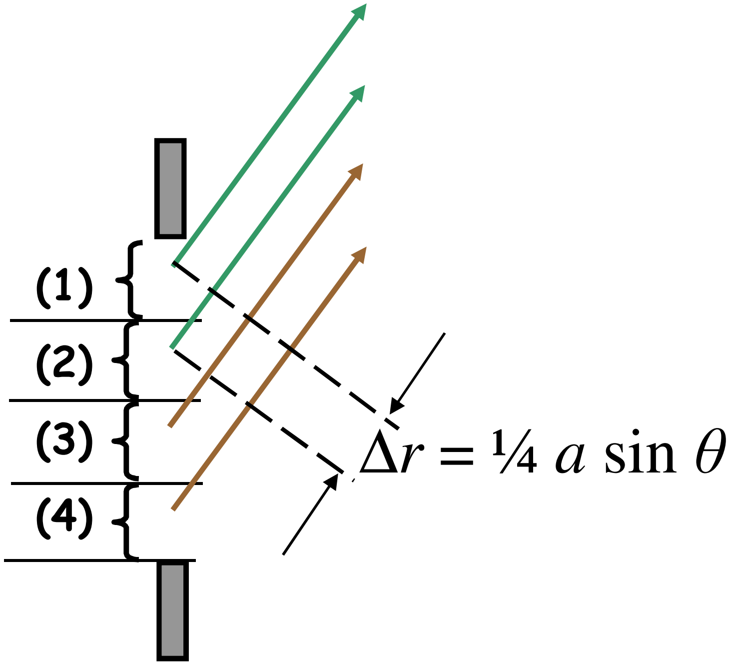
$$\tfrac{1}{4}\, a \sin\theta = \tfrac{1}{2}\lambda$$

(or $a \sin\theta = 2\lambda$):

Now rays from points a/4 apart will be $\frac{1}{2}$ cycle out of phase, and will interfere destructively:

(1) cancels (2)
(3) cancels (4)

and we get another minimum.



For any non-zero integer m, there will be complete destructive interference at angle θ given by

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

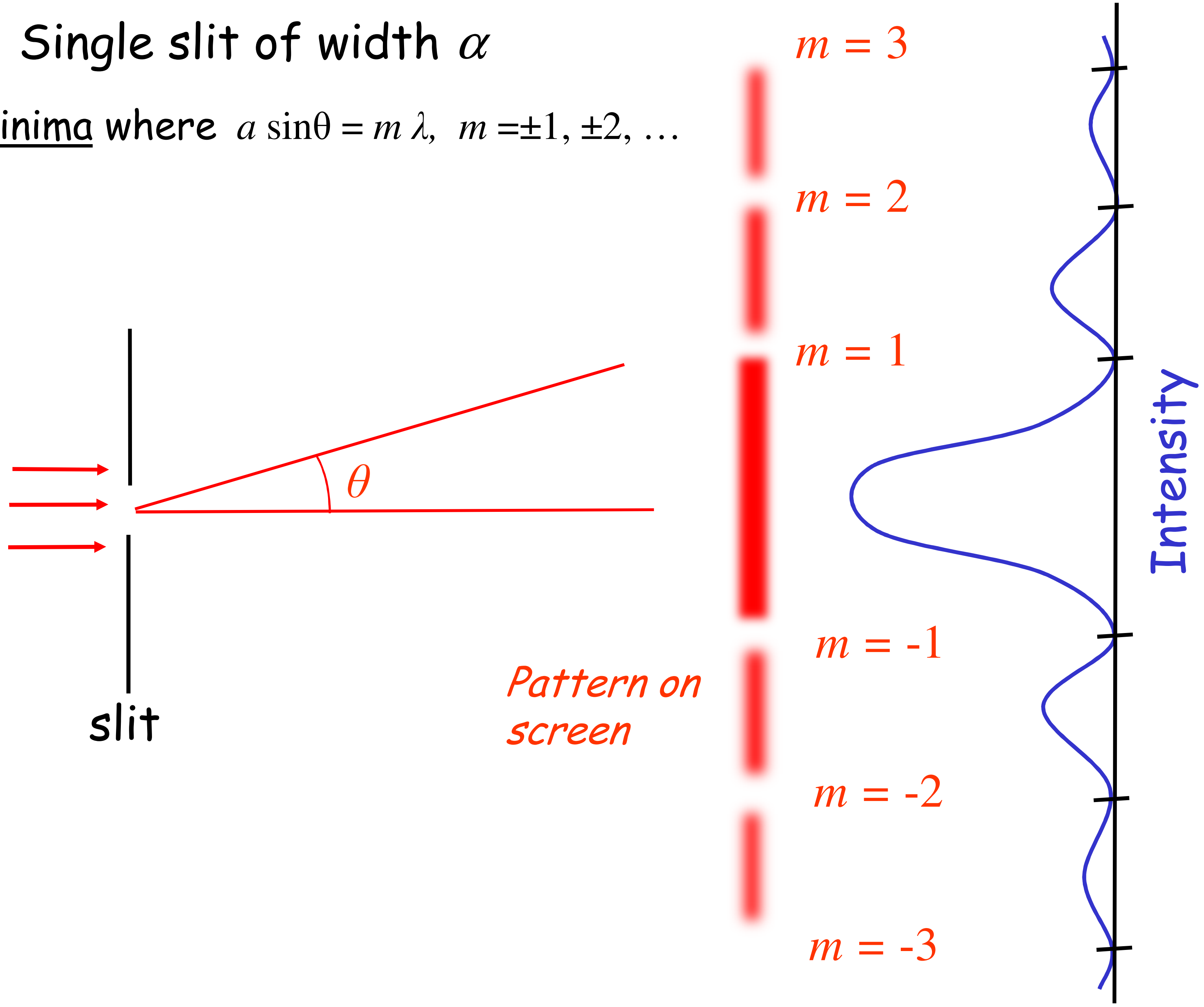
Result: **Minima** when

$$\boxed{\sin\theta = m\lambda/a}$$

$m = \pm 1, \pm 2, \pm 3, \ldots$
(but **not** $m = 0$)

Single slit of width α

Minima where $a \sin\theta = m\lambda$, $m = \pm 1, \pm 2, \ldots$



Notes:

1) Central peak is twice as wide, much brighter (~ 90% of light)

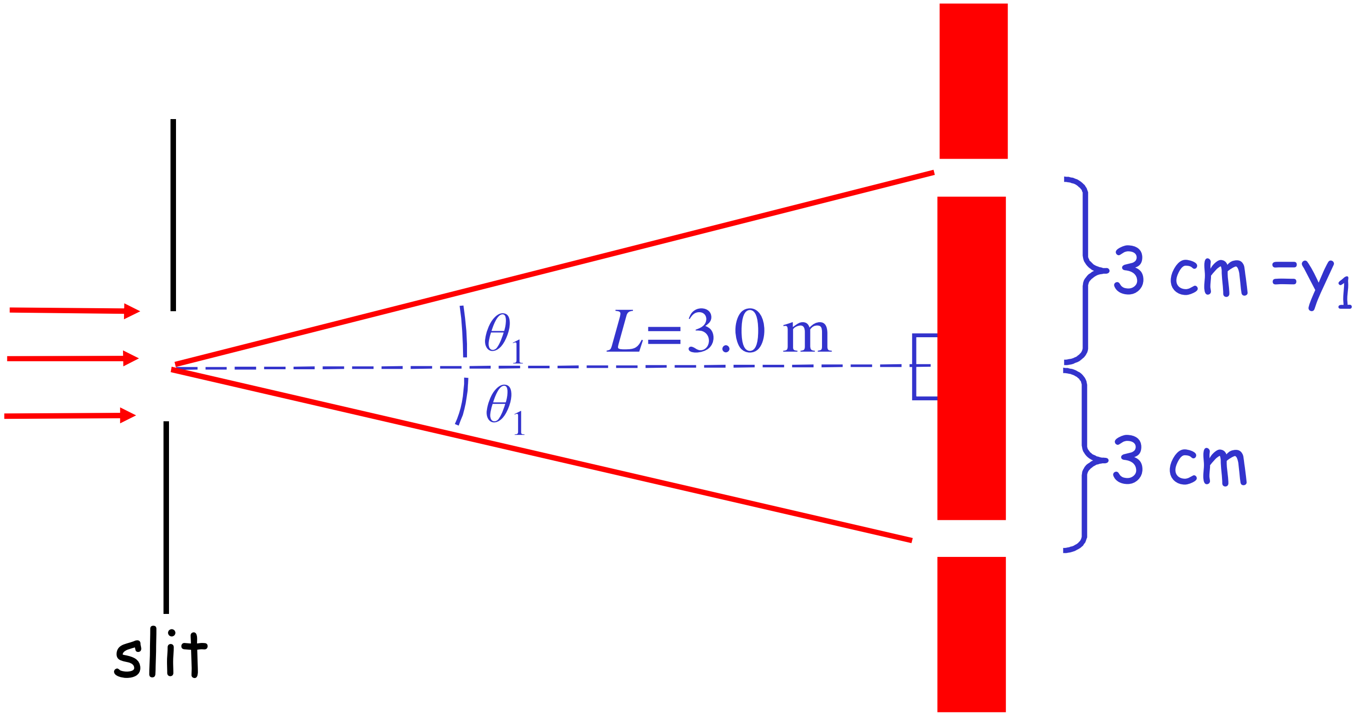
2) Side peaks get fainter as we move to higher orders m

3) Minima are at $\sin\theta = m\dfrac{\lambda}{a}, \quad m \neq 0$

4) Maxima are approximately halfway between the minima.

Example

λ = 600 nm; central peak is 6cm wide on a screen 3m away. How wide is the slit?



Quiz:

Above is the pattern on the screen from a single slit 0.1 mm wide. If we had two slits, each 0.1 mm wide, and separated by 0.3 mm (between centres), what would we see on the screen?

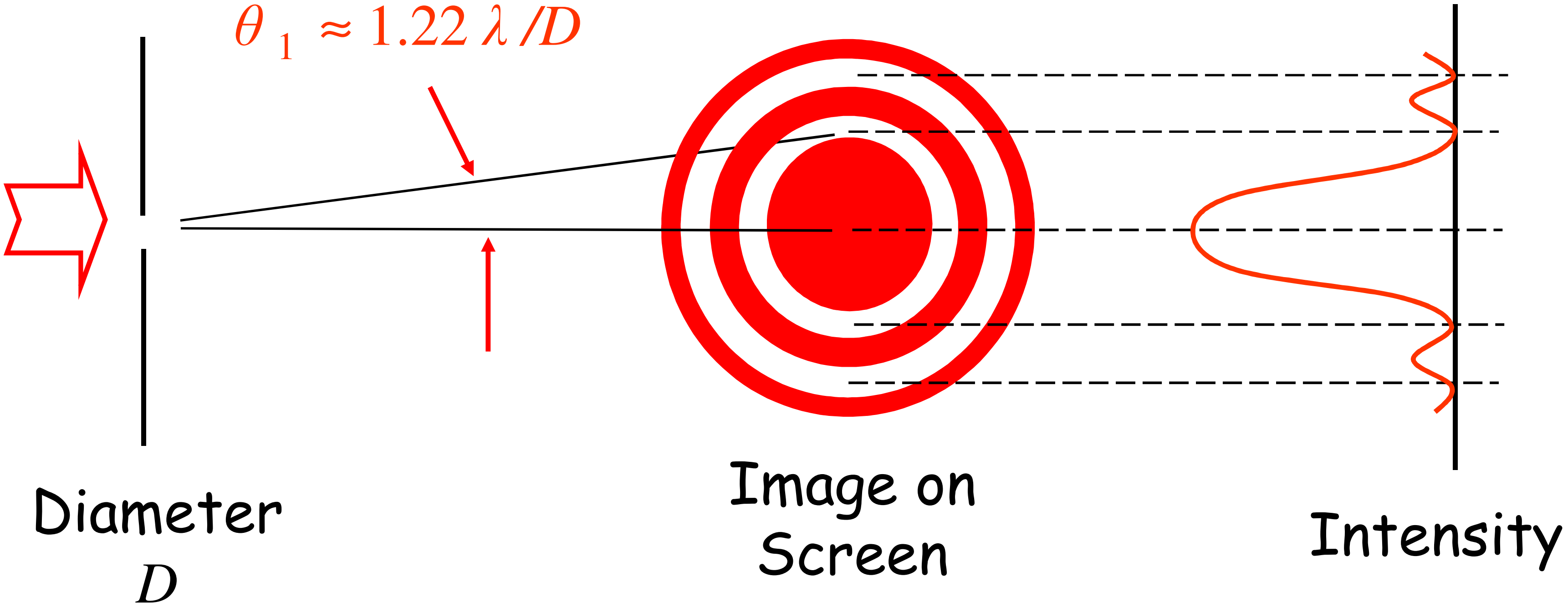
A

B

C

D

Diffraction through a **circular** aperture:



The angle θ_1 from the centre to first dark ring (“angular radius” of central spot) is about $1.22\,\lambda/D$ radians.

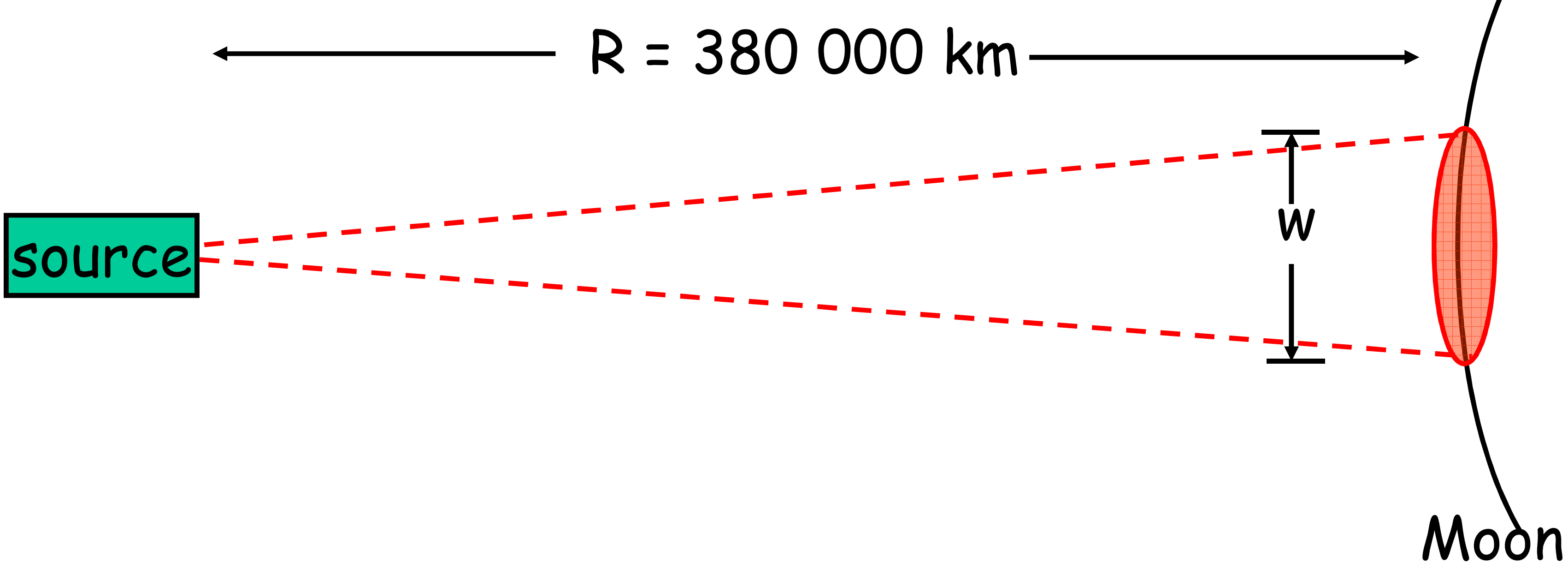
Quiz:

What would the *central spot* look like if white light were used for the beam?

A) Blue in the centre and red around the edge
B) Red in the centre and blue around the edge
C) White in the centre and red around the edge

Example: *A telescope (diameter 1.2 m) is used in reverse to focus a laser ($\lambda = 600\ \mathrm{nm}$) on the moon.*

Find: Minimum diameter of spot on moon.



Answer: w = 460 m

Quiz:

The ruby laser used actually has λ = 694 nm, instead of 600 nm. So the actual spot diameter is closer to:

A) 400 m

B) 500 m

Question:

What approximate (order of magnitude) spot diameter, on the moon, could we expect with the helium-neon laser used for the lecture demonstrations (pointed directly at the moon, without using a telescope), if the laser beam is limited only by diffraction?