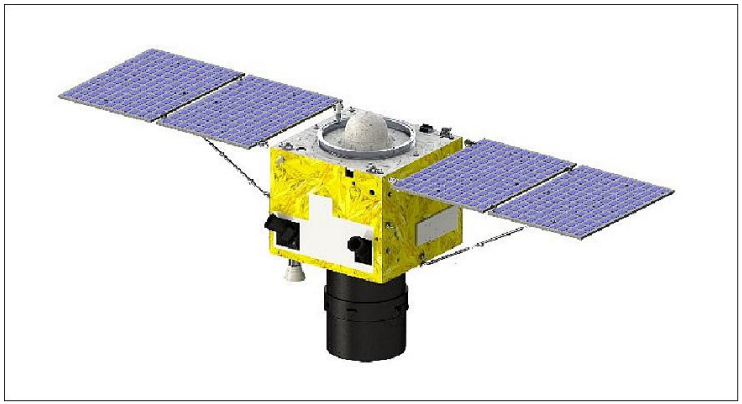
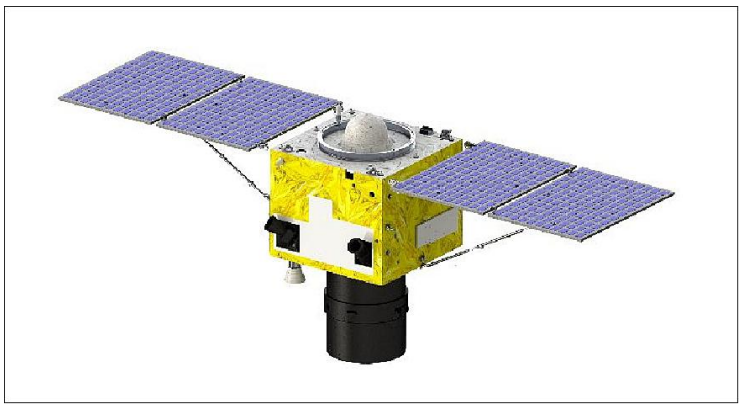
The Limits of Sight 1

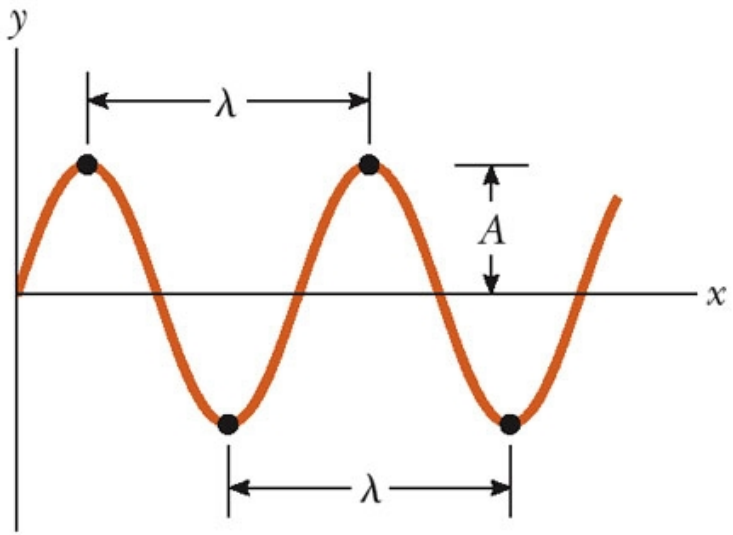
The SuperView 1B satellite is a commercial satellite designed to take surveillance photographs for sale and has been active since 2016. The cost for photos from the satellite archive is as low \$14. The aperture of the camera on the satellite is $a = 0.42\ m$ and the satellite operates $L = 530\ km$ above the Earth. What is the size of the smallest object visible to the camera? Visible light covers a range of wavelengths of $\lambda \approx 400 - 700\ nm$. What is the size of the smallest object visible to human eyes?



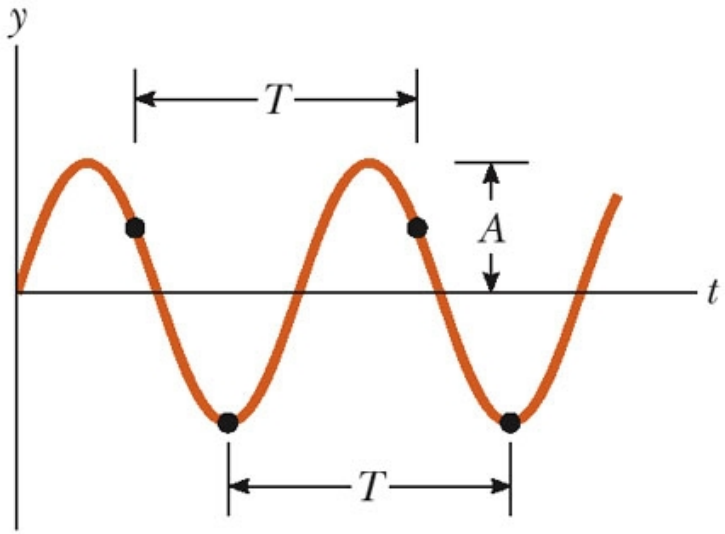
The Limits of Sight 2

cial satellite designed to take
been active since 2016. The cost
low $14. The aperture of the
d the satellite operates
ıe size of the smallest object
s a range of wavelengths of
he smallest object visible to





(a)



(b)

$$y = A\sin\left(kx - \omega t + \phi_0\right)$$

Demo is here.

Electromagnetic Induction 4

Electromagnetic Induction 5

- What happens when a static $\vec{B}$ field is near a coil?

Lenz's Law demo is here.

Electromagnetic Induction 6

- What happens when a static $\vec{B}$ field is near a coil? Nothing

Lenz's Law demo is here.

Electromagnetic Induction 7

- What happens when a static $\vec{B}$ field is near a coil? Nothing
- What happens when the magnet is pulled away?

Lenz's Law demo is here.

Electromagnetic Induction 8

- What happens when a static $\vec{B}$ field is near a coil? Nothing
- What happens when the magnet is pulled away? Current

Lenz's Law demo is here.

Electromagnetic Induction 9

- What happens when a static $\vec{B}$ field is near a coil? Nothing
- What happens when the magnet is pulled away? Current
- Is there an $\vec{E}$ field?

Lenz's Law demo is here.

Electromagnetic Induction 10

- What happens when a static $\vec{B}$ field is near a coil? Nothing
- What happens when the magnet is pulled away? Current
- Is there an $\vec{E}$ field? Yes

Lenz's Law demo is here.

- What happens when a static $\vec{B}$ field is near a coil? Nothing
- What happens when the magnet is pulled away? Current
- Is there an $\vec{E}$ field? Yes

A changing $\vec{B}$ field creates an $\vec{E}$ field.

Lenz's Law demo is here.

Electromagnetic Induction 12

- What happens when a static $\vec{B}$ field is near a coil? Nothing
- What happens when the magnet is pulled away? Current
- Is there an $\vec{E}$ field? Yes

A changing $\vec{B}$ field creates an $\vec{E}$ field.

- How do you create a $\vec{B}$ field?

Lenz's Law demo is here.

- What happens when a static $\vec{B}$ field is near a coil? Nothing
- What happens when the magnet is pulled away? Current
- Is there an $\vec{E}$ field? Yes

A changing $\vec{B}$ field creates an $\vec{E}$ field.

- How do you create a $\vec{B}$ field? A current (and an $\vec{E}$ field)

Lenz's Law demo is here.

- What happens when a static $\vec{B}$ field is near a coil? Nothing
- What happens when the magnet is pulled away? Current
- Is there an $\vec{E}$ field? Yes

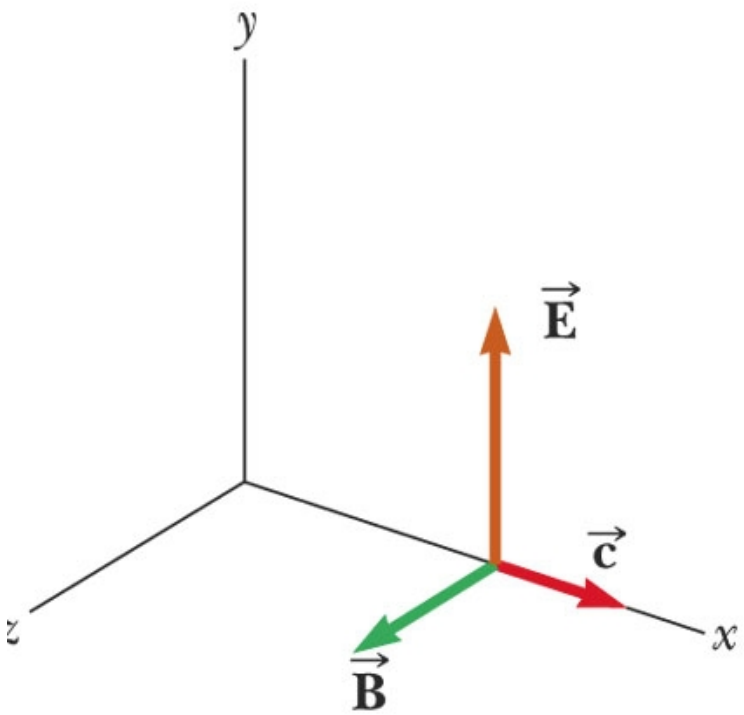
A changing $\vec{B}$ field creates an $\vec{E}$ field.

- How do you create a $\vec{B}$ field? A current (and an $\vec{E}$ field)

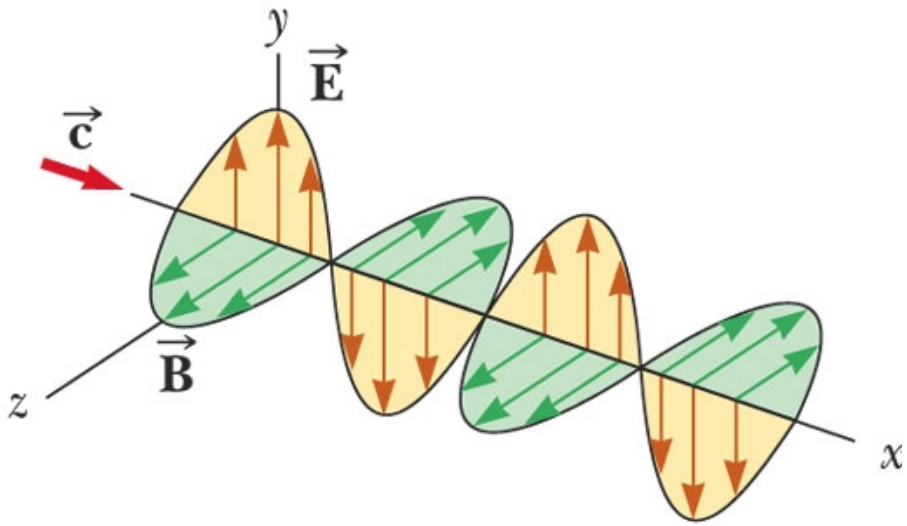
A changing $\vec{E}$ field can create a changing $\vec{B}$ field.

Lenz's Law demo is here.

Electromagnetic Waves 15

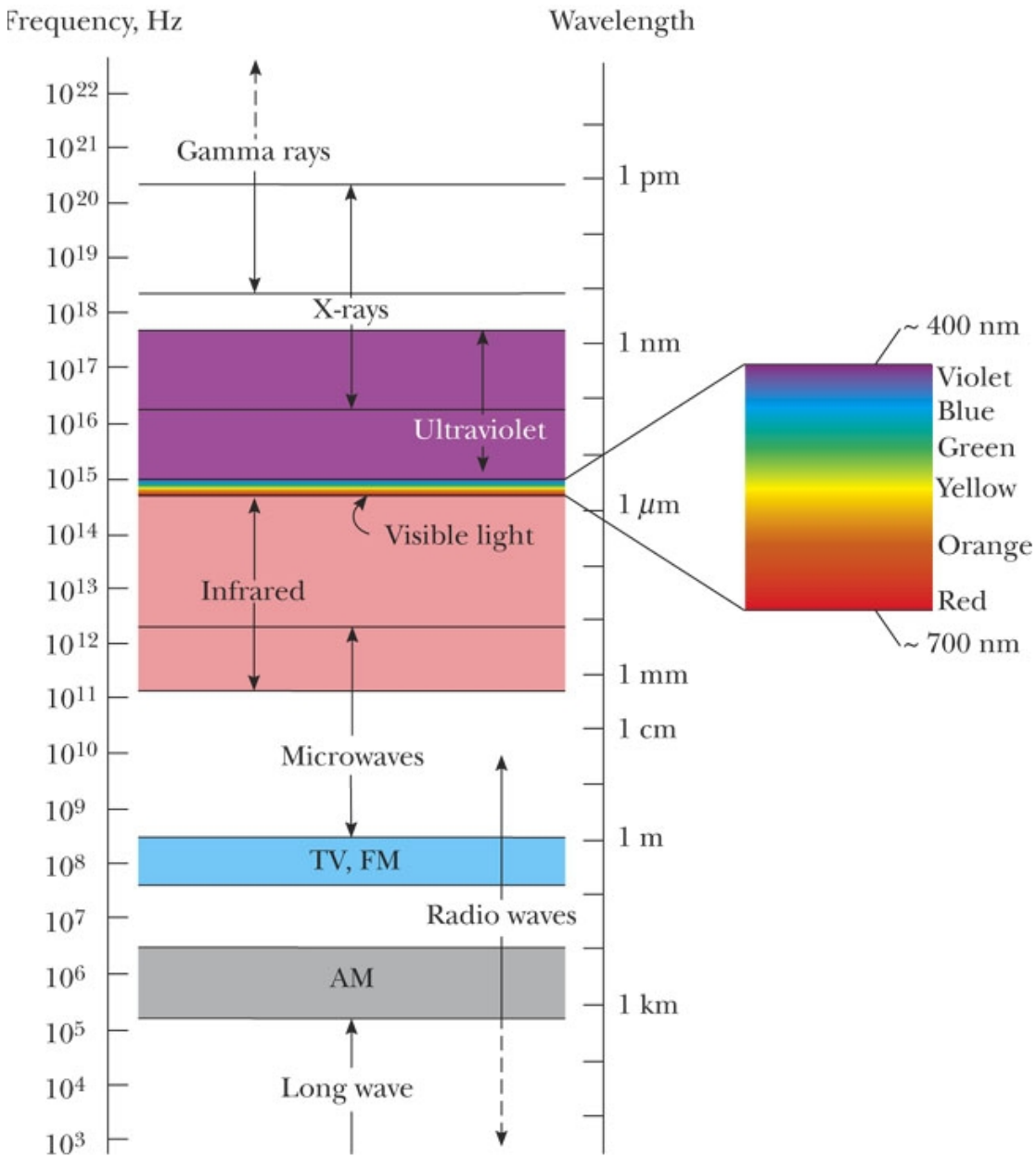


(a)

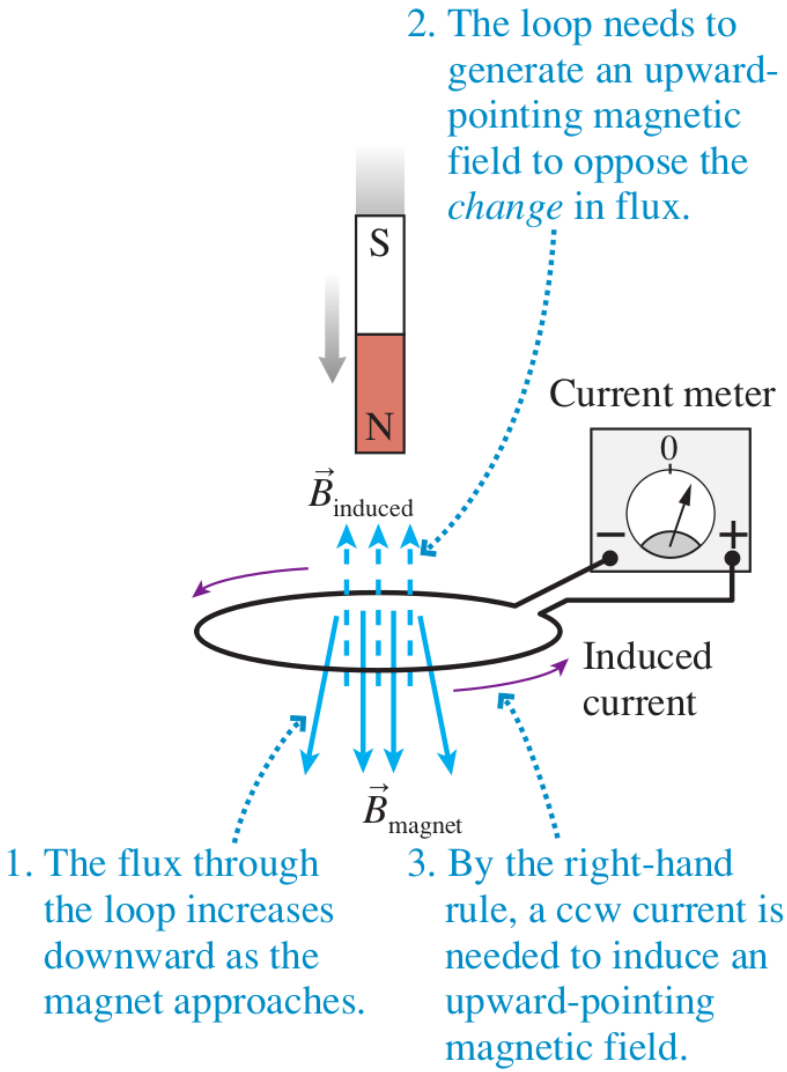


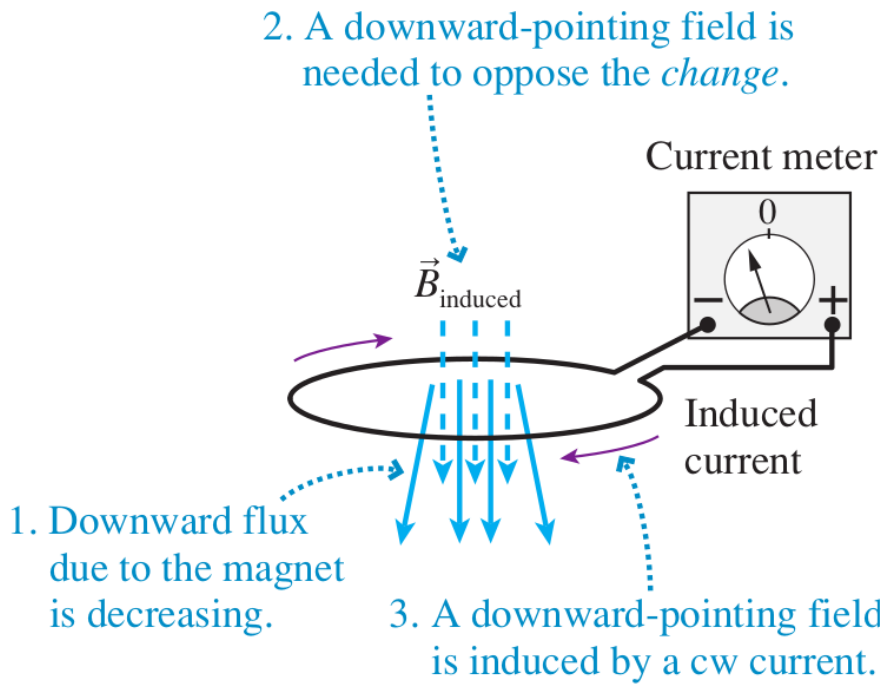
(b)

Electromagnetic Spectrum 16



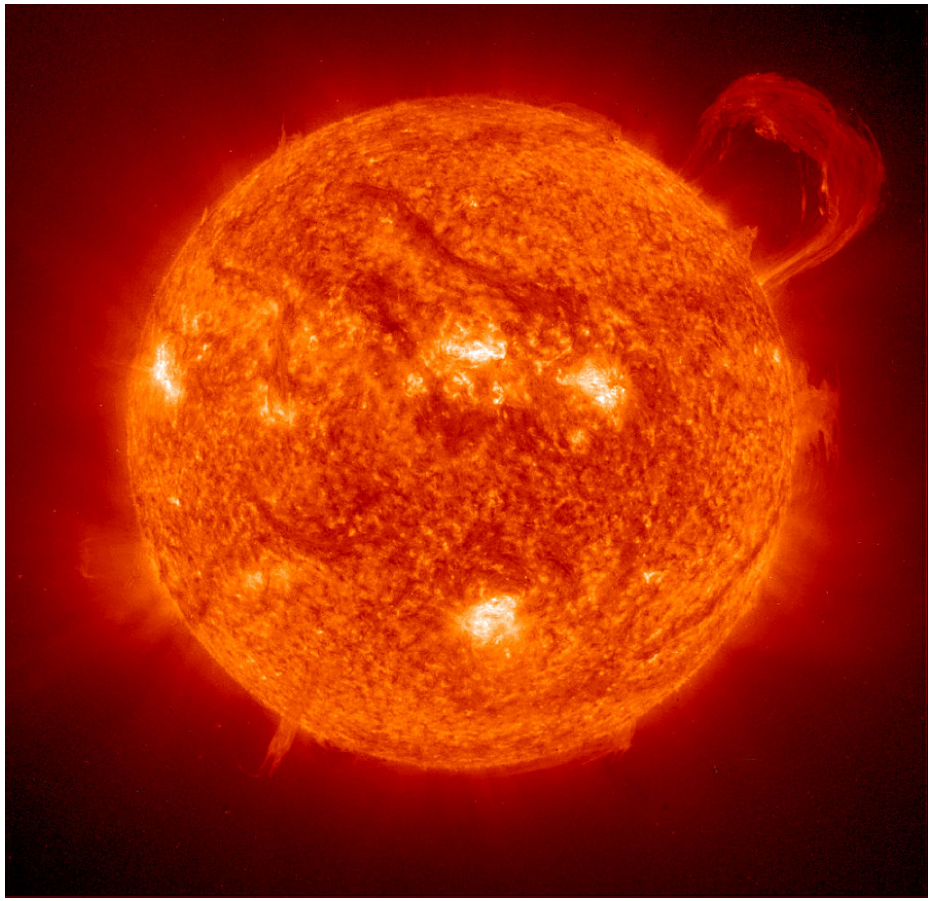
Lenz's Law 17


2. The loop needs to generate an upward-pointing magnetic field to oppose the *change* in flux.
S
N
Current meter
0
$\vec{B}_{\text{induced}}$
Induced current
$\vec{B}_{\text{magnet}}$
1. The flux through the loop increases downward as the magnet approaches.
3. By the right-hand rule, a ccw current is needed to induce an upward-pointing magnetic field.


2. A downward-pointing field is needed to oppose the *change*.
Current meter
0
$\vec{B}_{\text{induced}}$
Induced current
1. Downward flux due to the magnet is decreasing.
3. A downward-pointing field is induced by a cw current.

The Electric Field of Sunlight 18

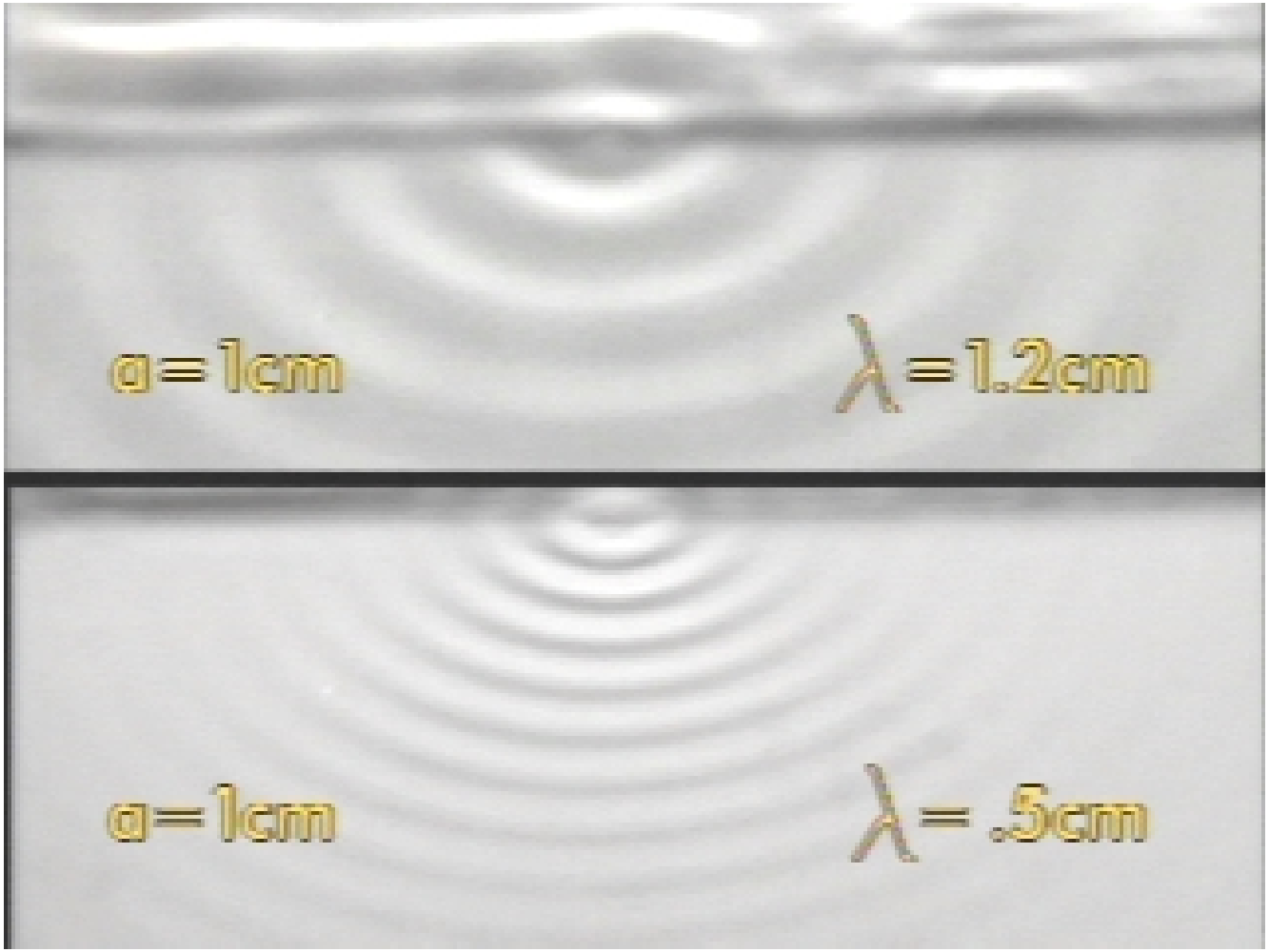
The intensity of sunlight reaching the Earth is called the solar constant (which is not really constant) and has a value of $I_s = 1366\ J/s - m^2$. What is the size of the electric field in sunlight? How does this compare with the typical fields we use in lab ($|\vec{E}| \approx 10\ N/C$)?



What Happens When Waves Hit Holes? 19

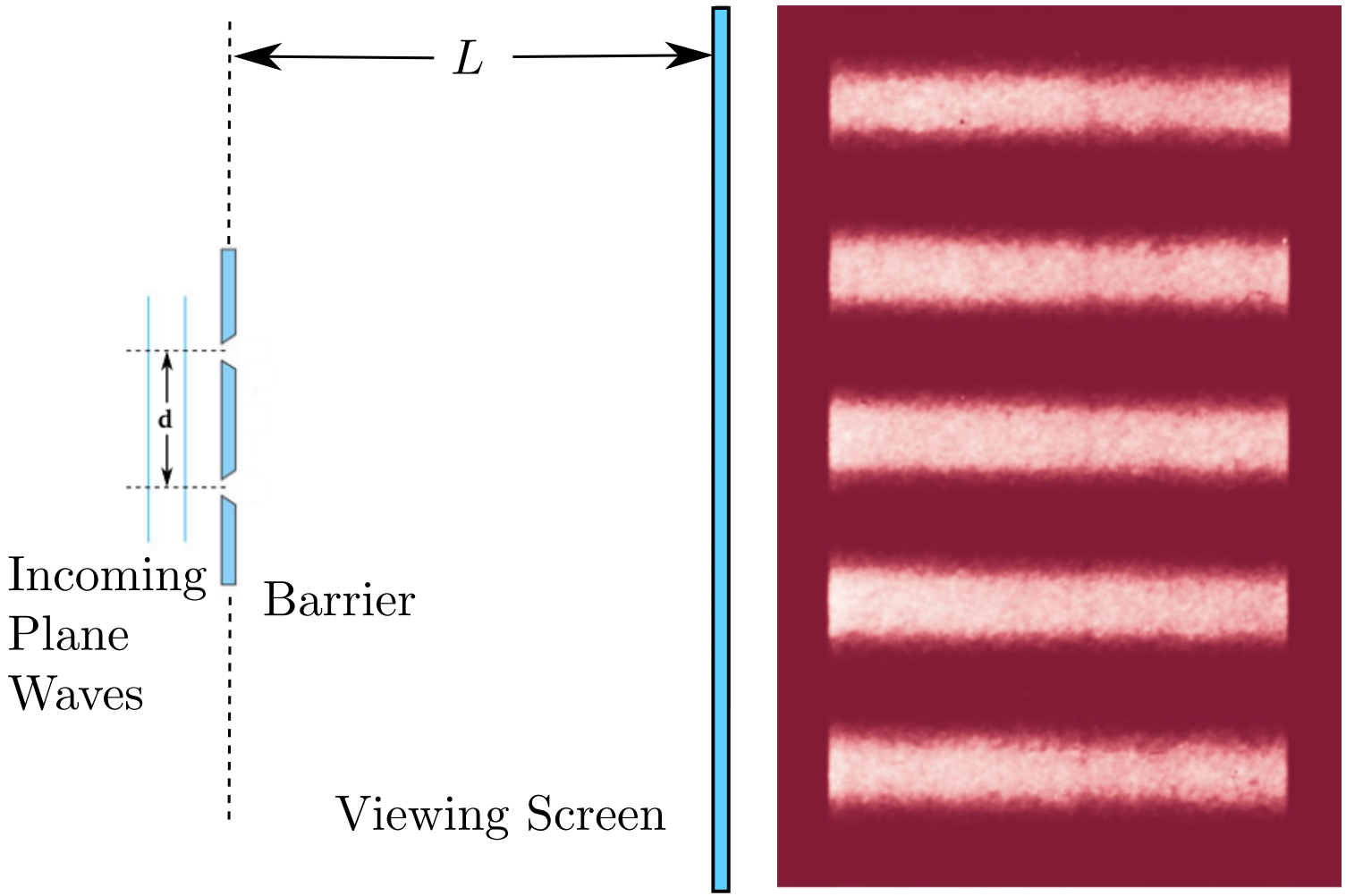
The videos are here and here. The simulation is here.

What Happens When Waves Hit Holes? 20

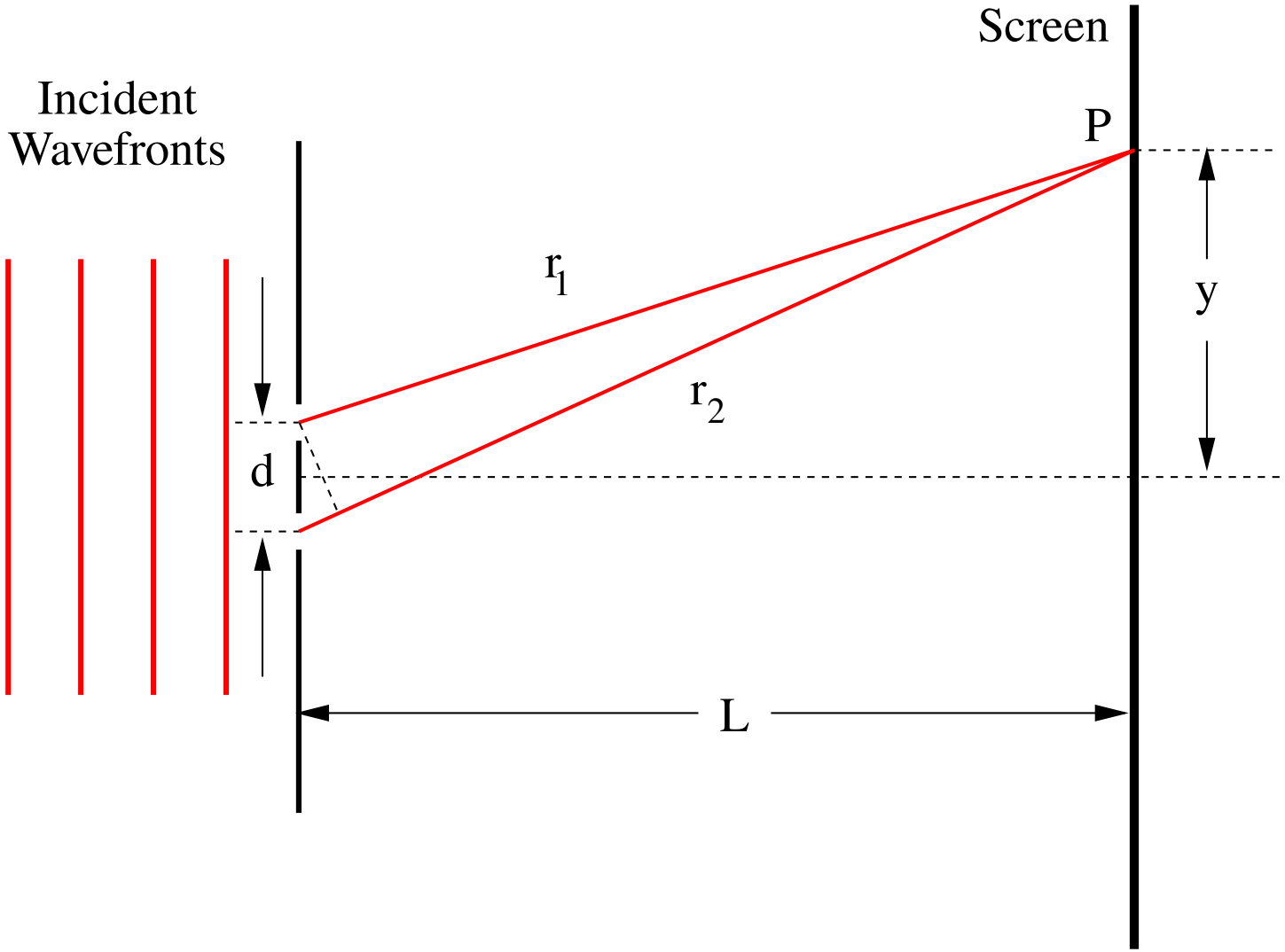


The videos are here and here. The simulation is here.

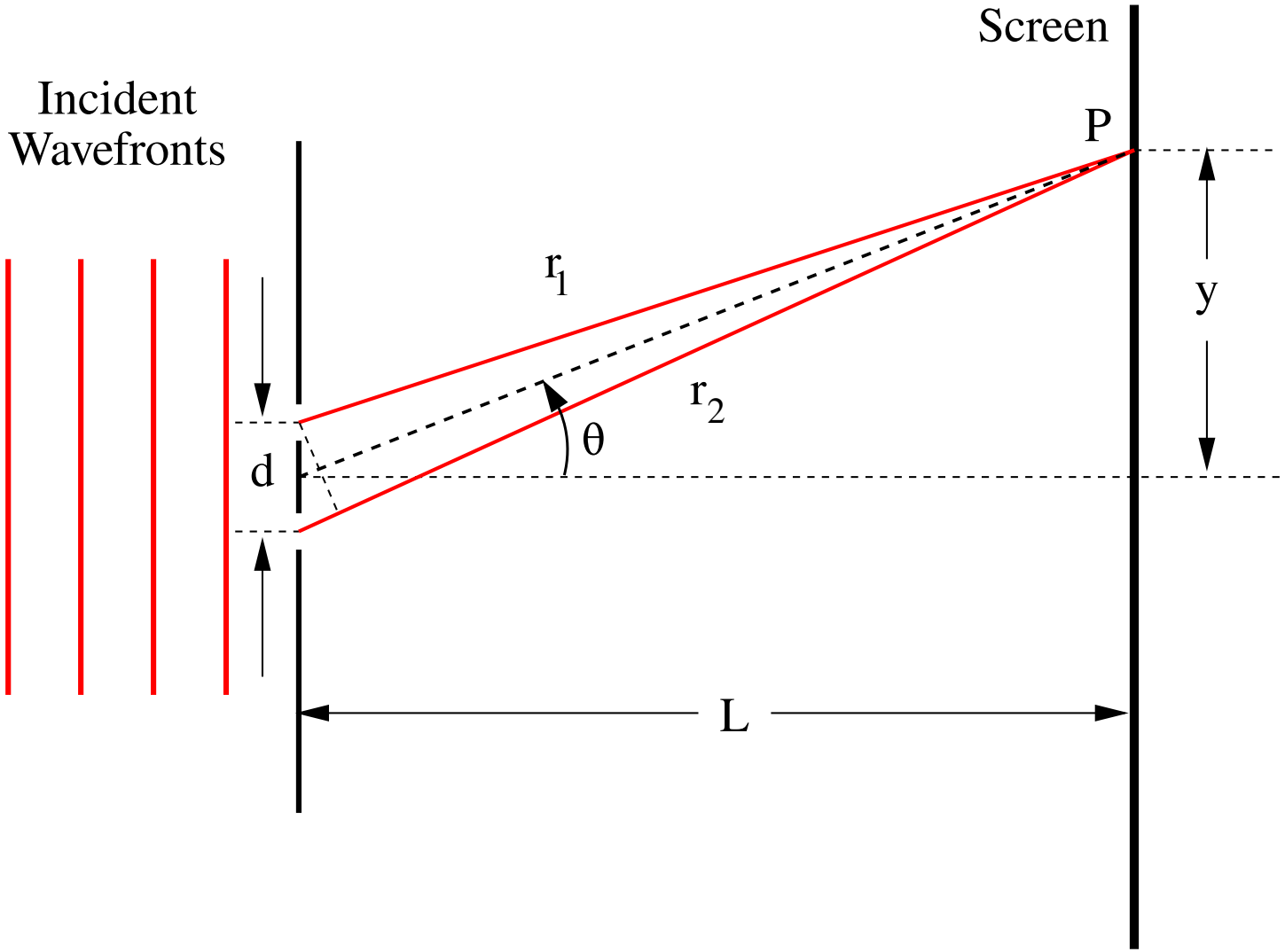
Double Slit Interference of Light 21



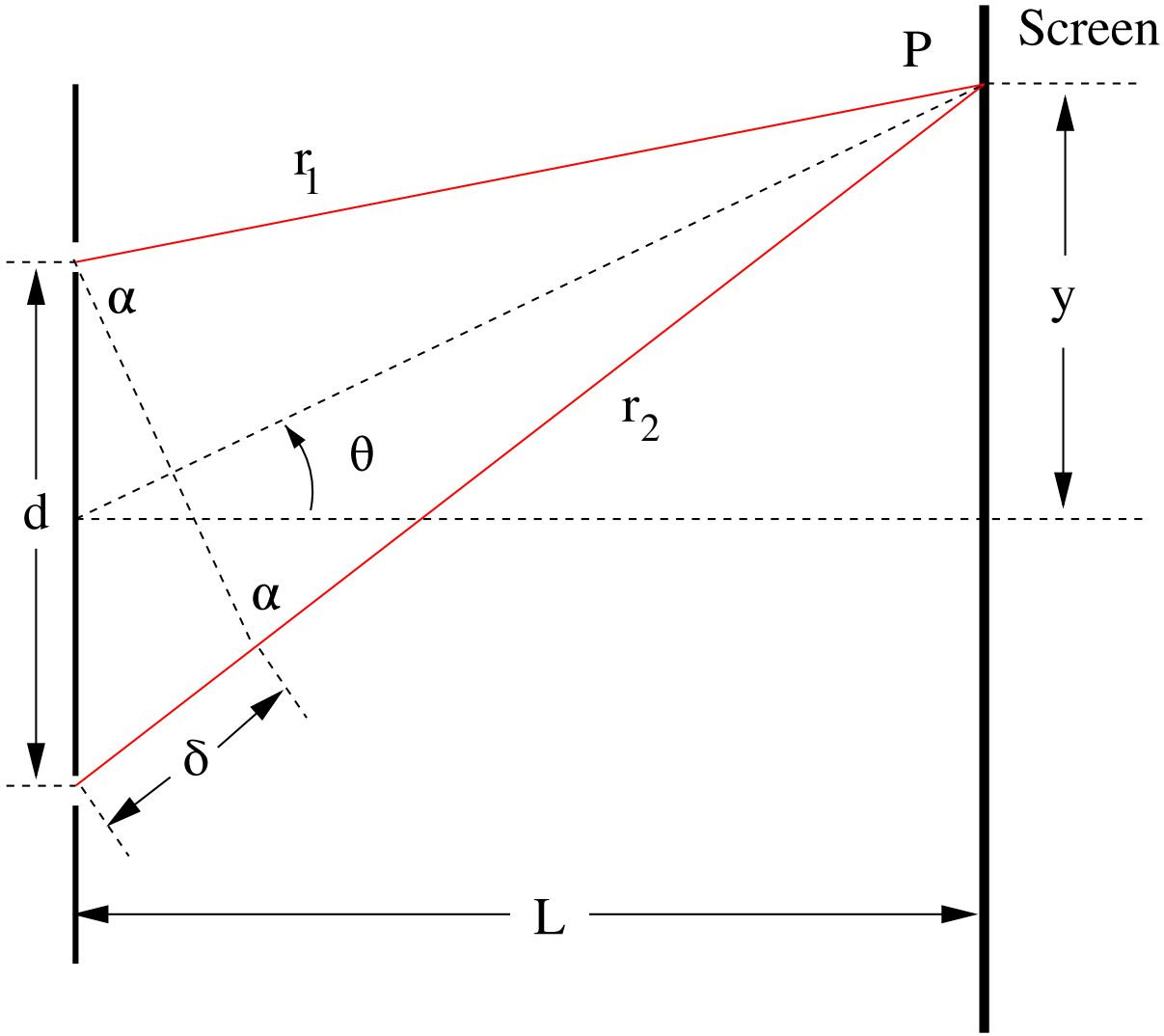
Double Slit Interference



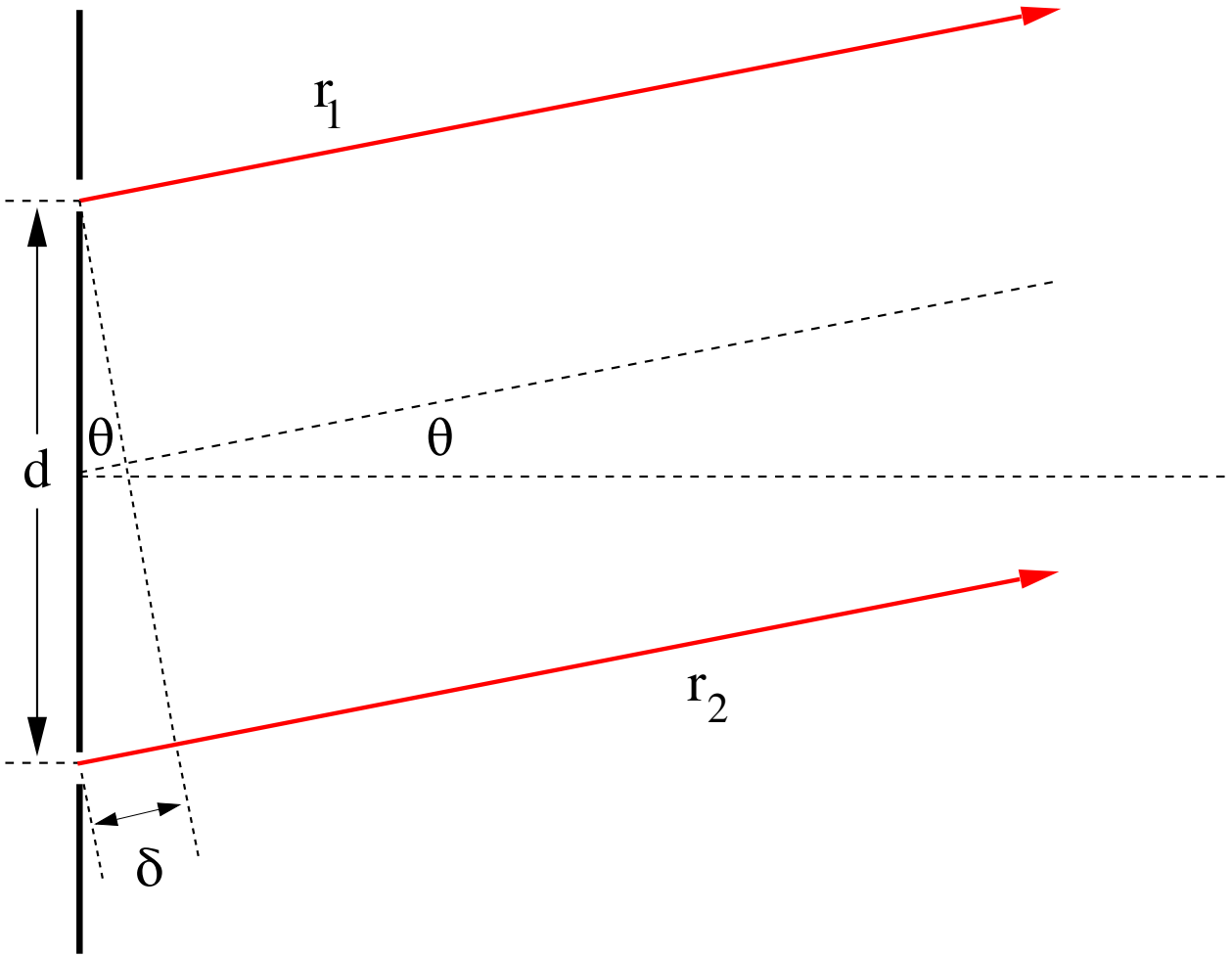
Double Slit Interference



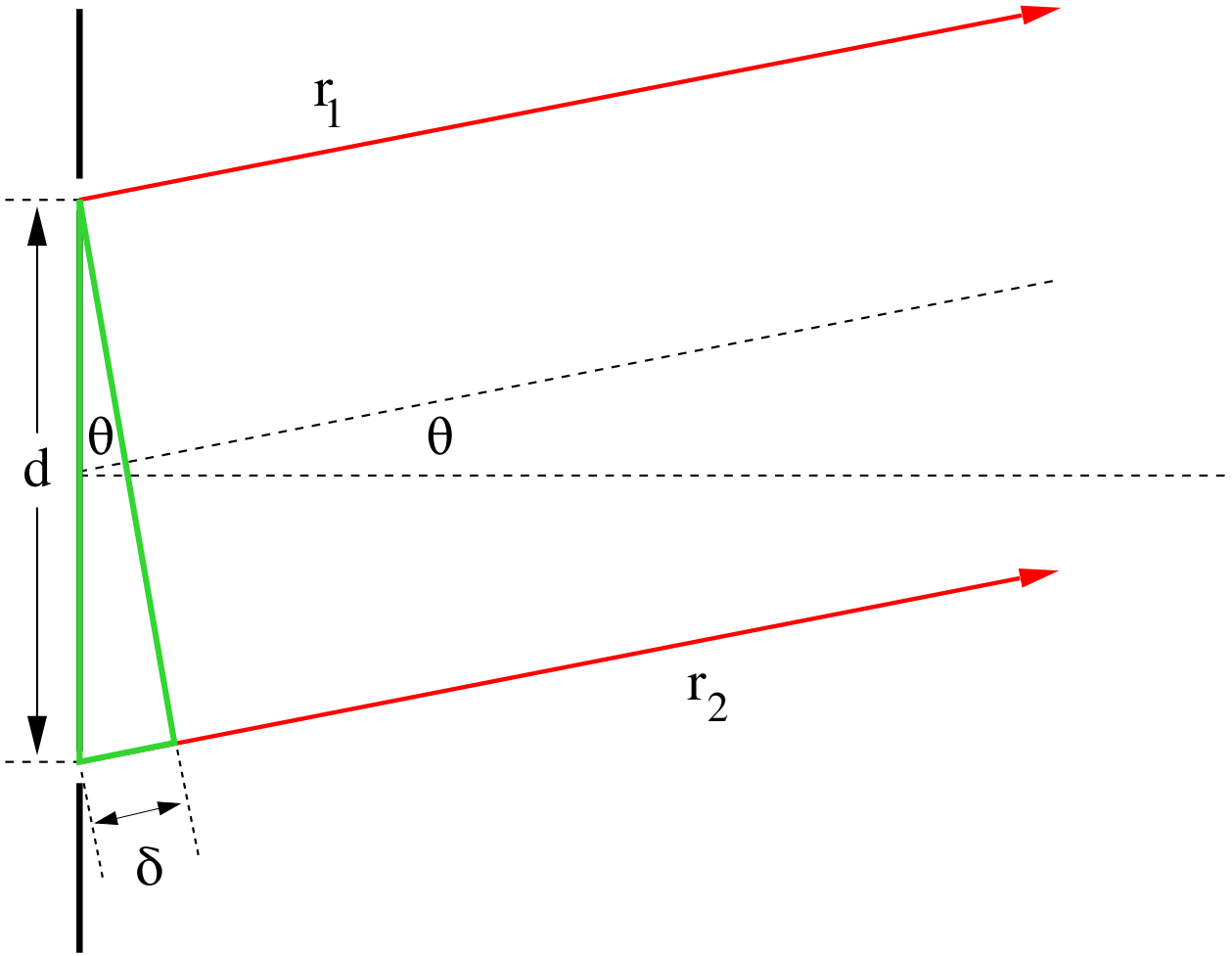
Double Slit Interference



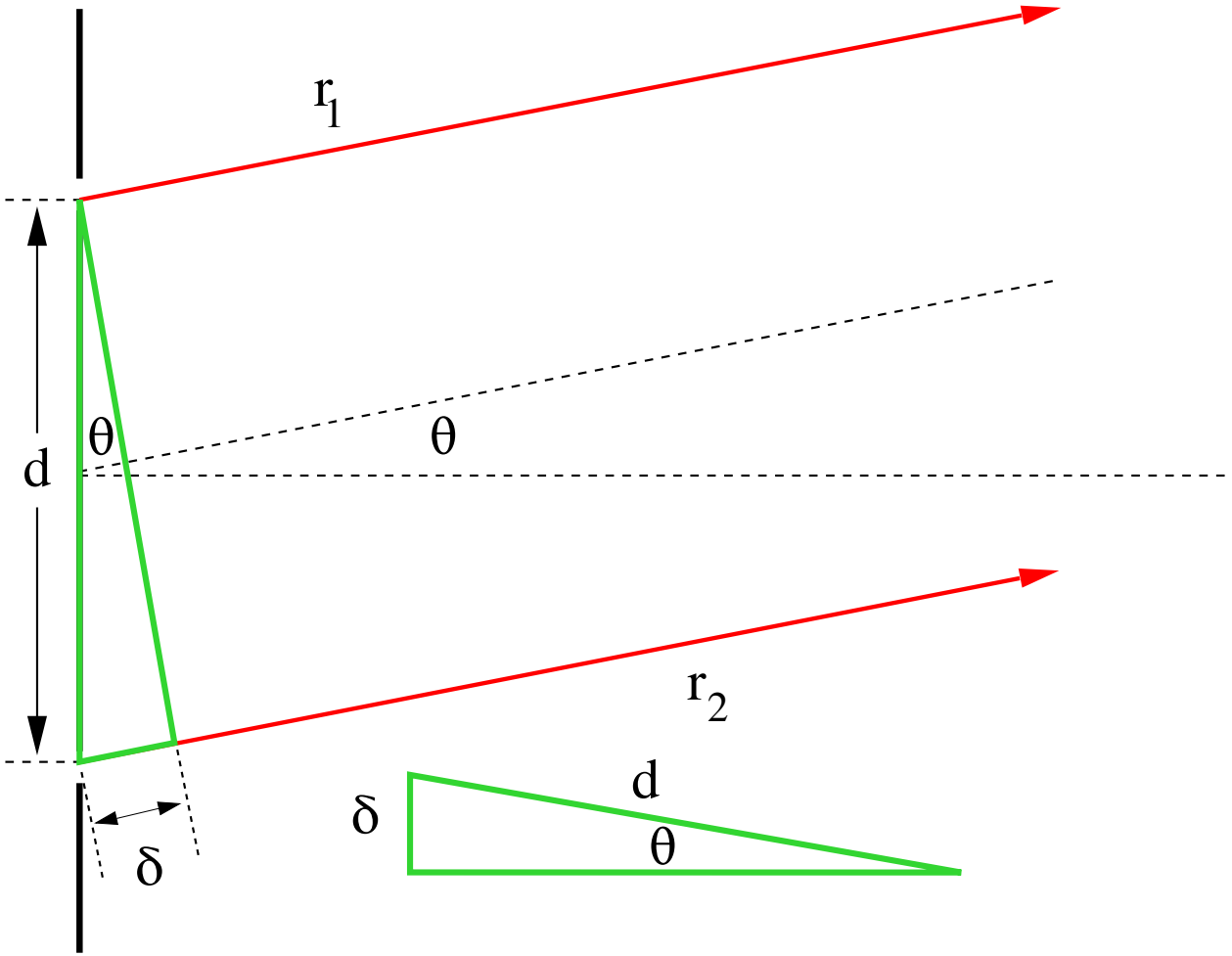
Double Slit Interference

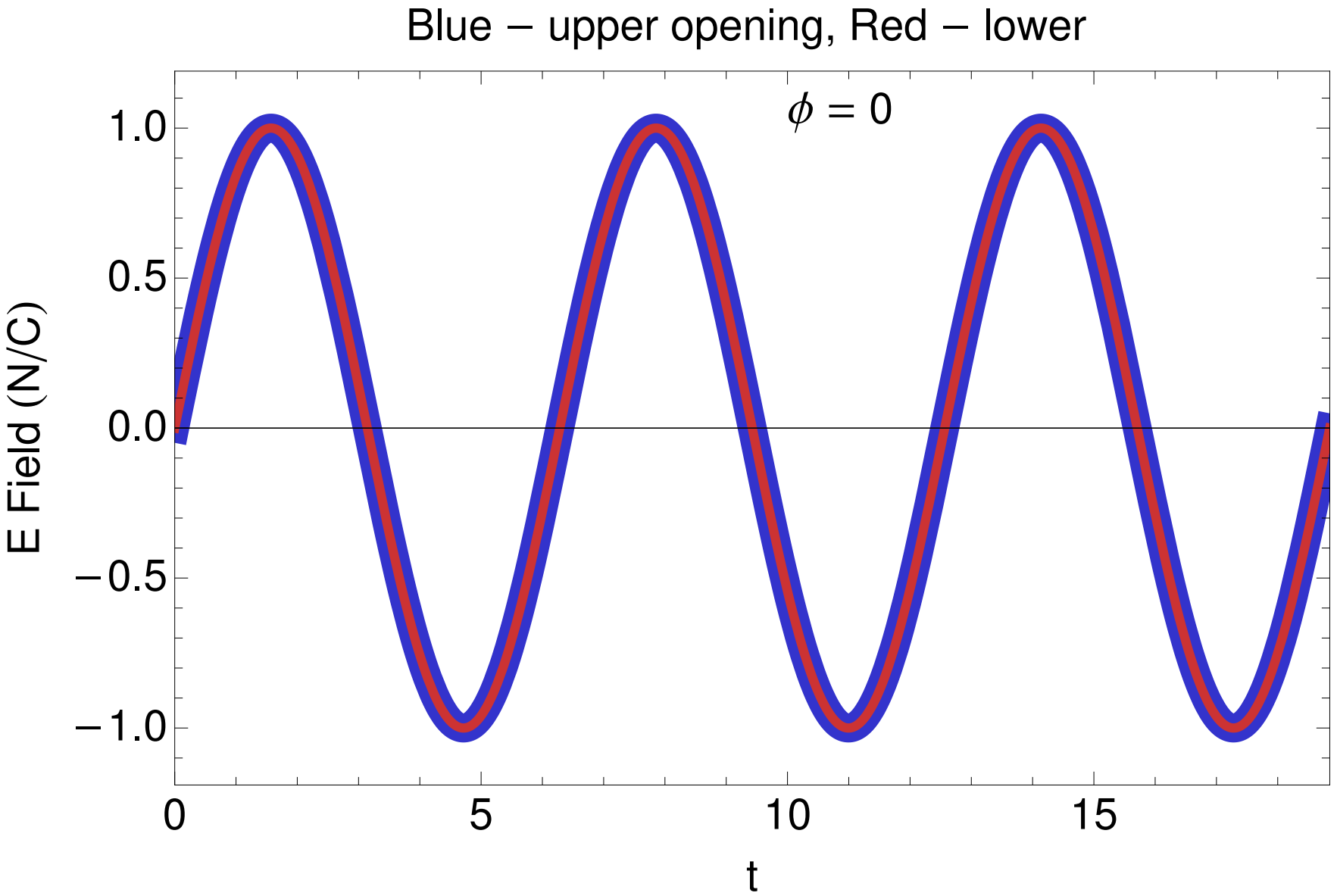


Double Slit Interference

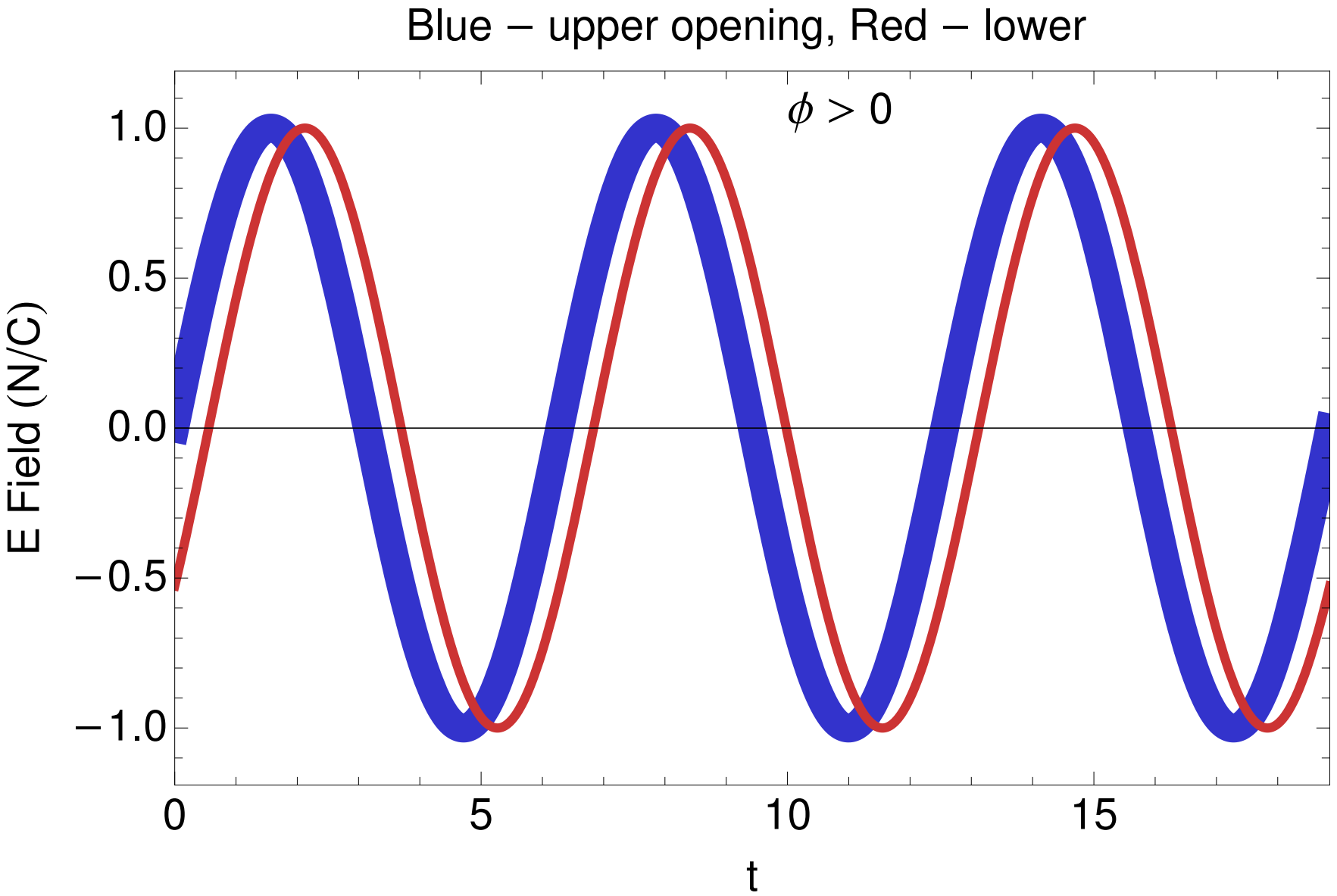


Double Slit Interference

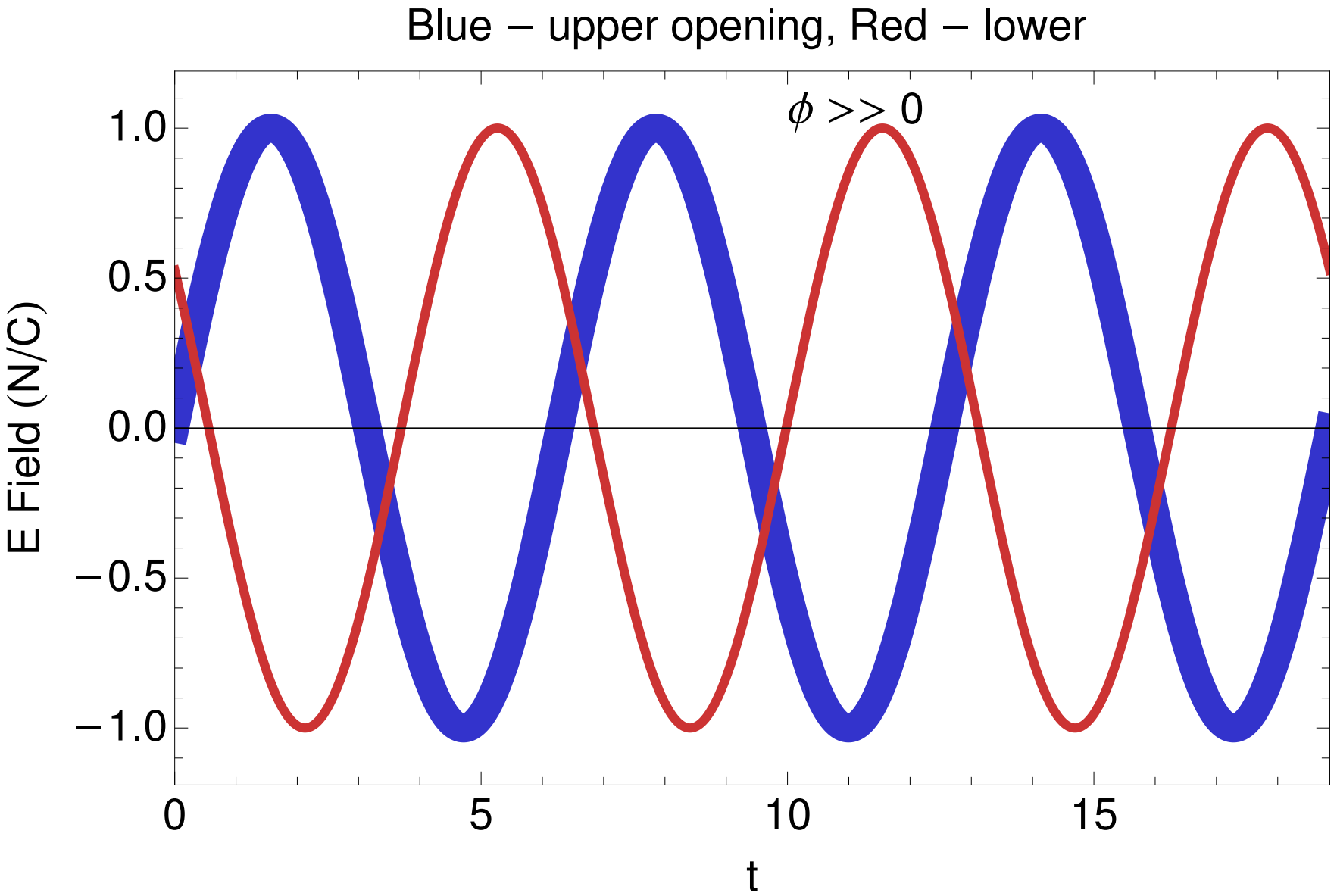



Blue – upper opening, Red – lower
$\phi = 0$
E Field (N/C)
1.0
0.5
0.0
−0.5
−1.0
0
5
10
15
t

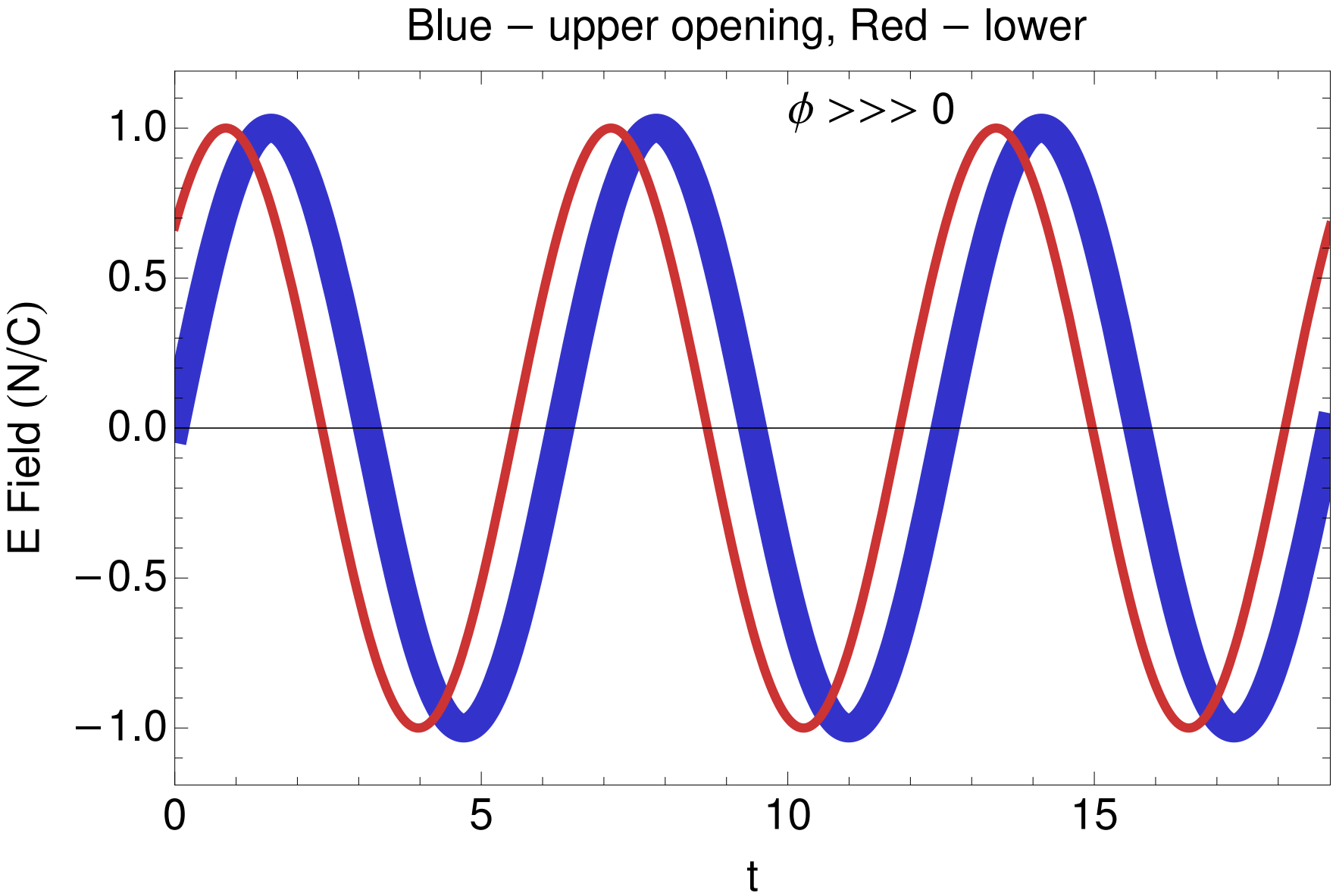
Double slit, small y, δ 29



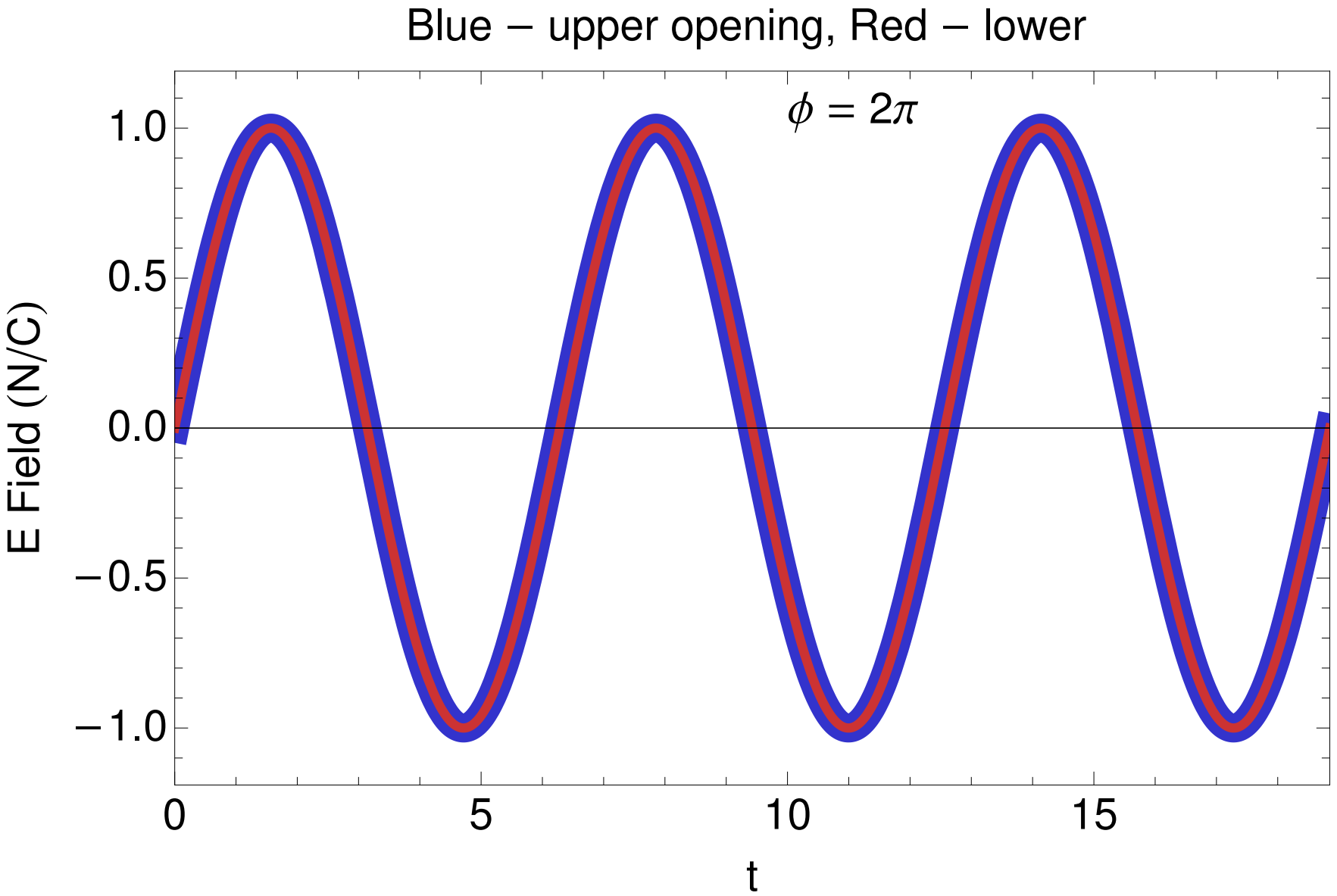
Double slit, increasing y, δ 30



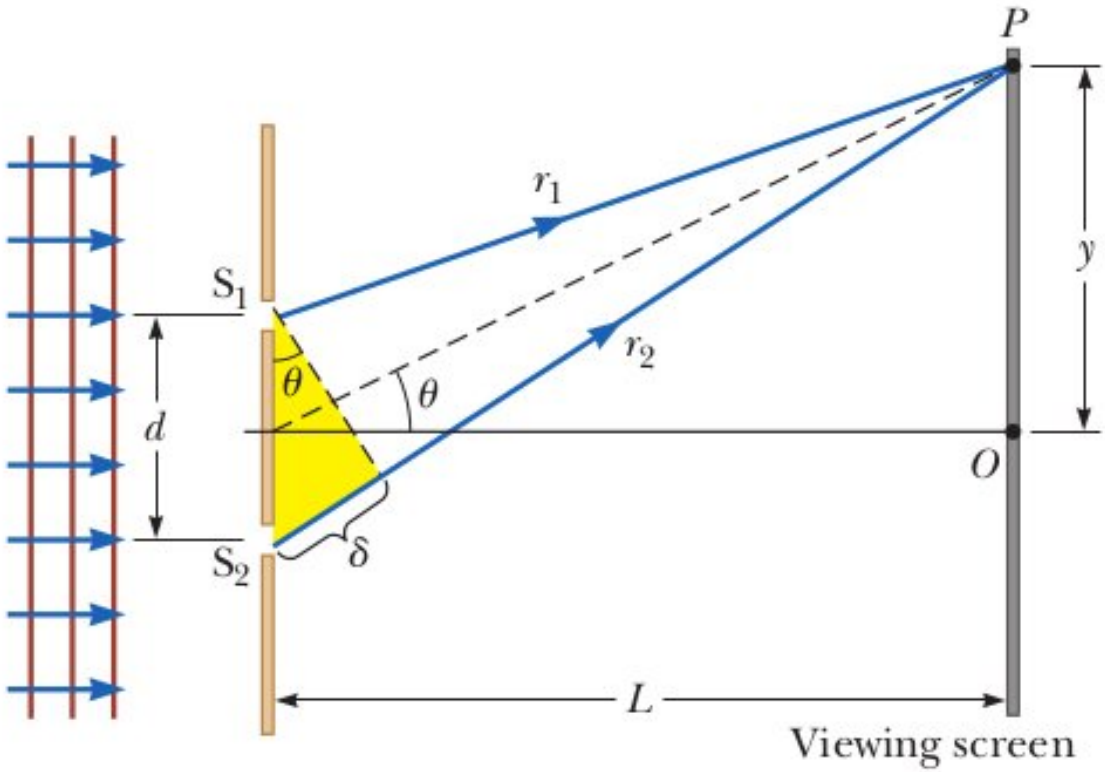
Double slit, increasing y, δ 31



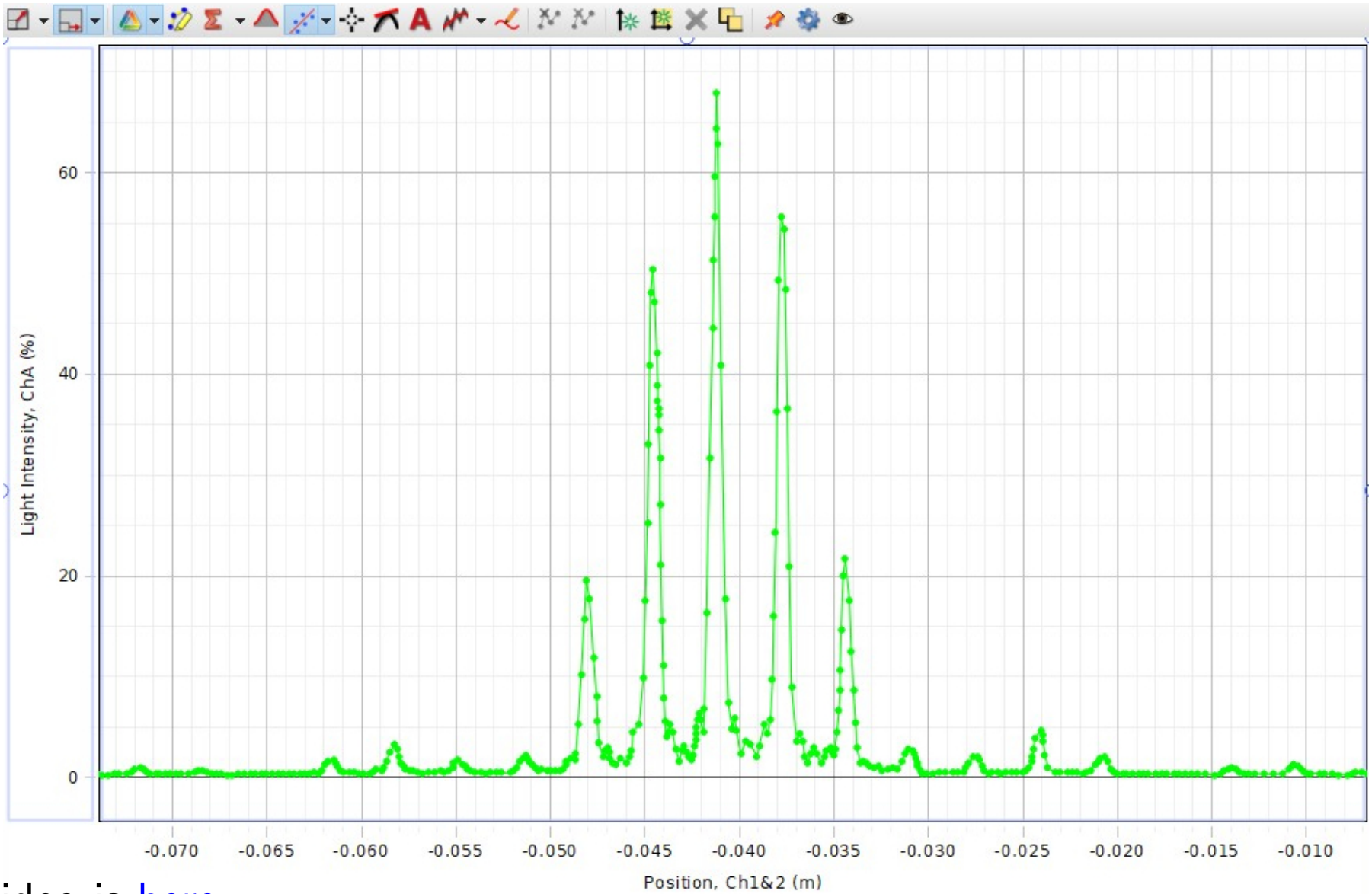
Double slit, increasing y, δ 32



A double-slit experiment is performed with $\lambda = 589\ nm$ light and a distance $L = 2.0\ m$ between the slits and the screen. The fifth interference maximum is observed at a distance $y = 4.0\ mm$ from the central maximum. What is the spacing d of the slits?



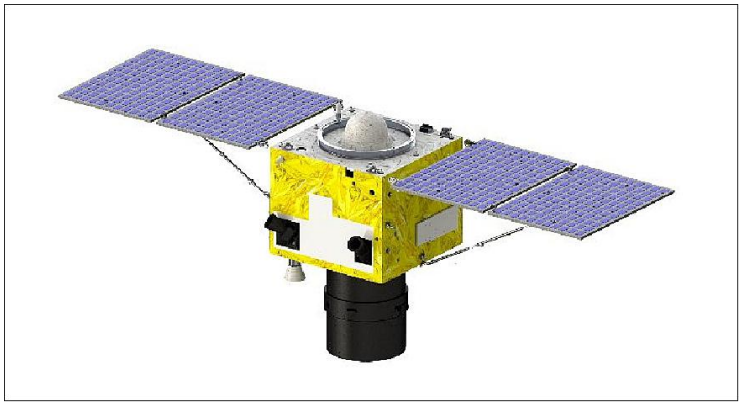
Lab Results 34



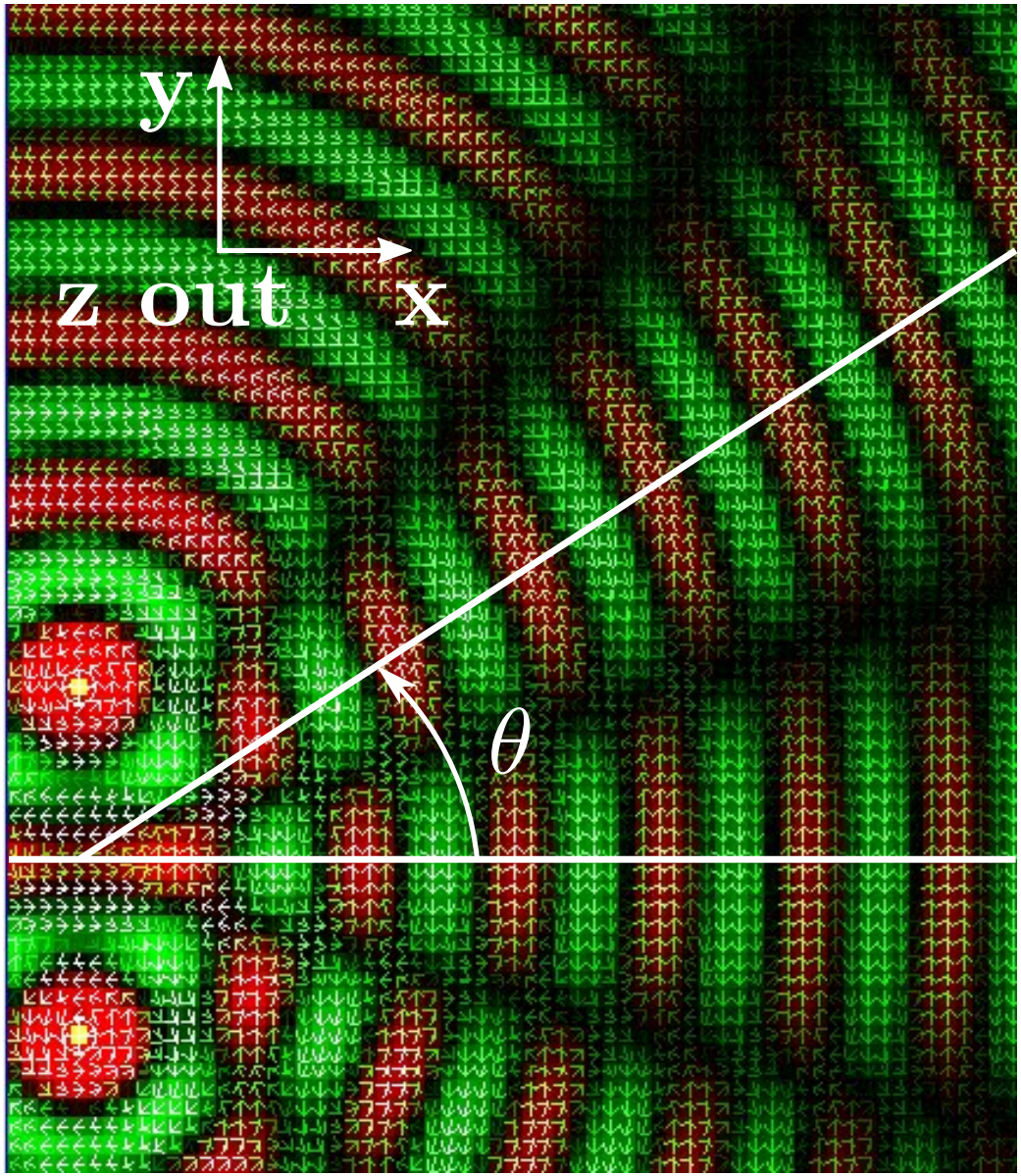
Video is here

The Limits of Sight 35

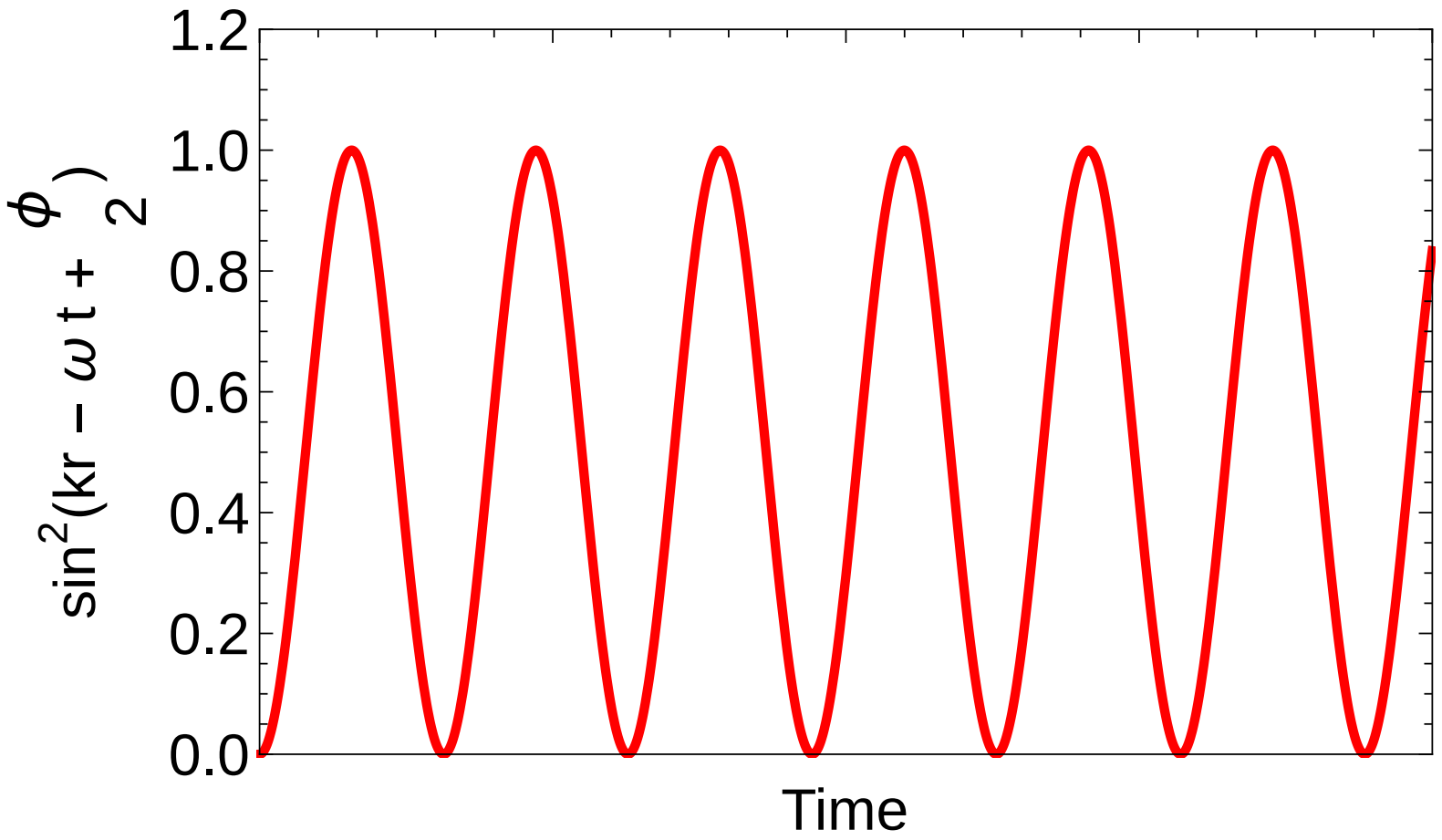
The SuperView 1B satellite is a commercial satellite designed to take surveillance photographs for sale and has been active since 2016. The cost for photos from the satellite archive is as low \$14. The aperture of the camera on the satellite is $a = 0.42\ m$ and the satellite operates $L = 530\ km$ above the Earth. What is the size of the smallest object visible to the camera? Visible light covers a range of wavelengths of $\lambda \approx 400 - 700\ nm$. What is the size of the smallest object visible to human eyes?



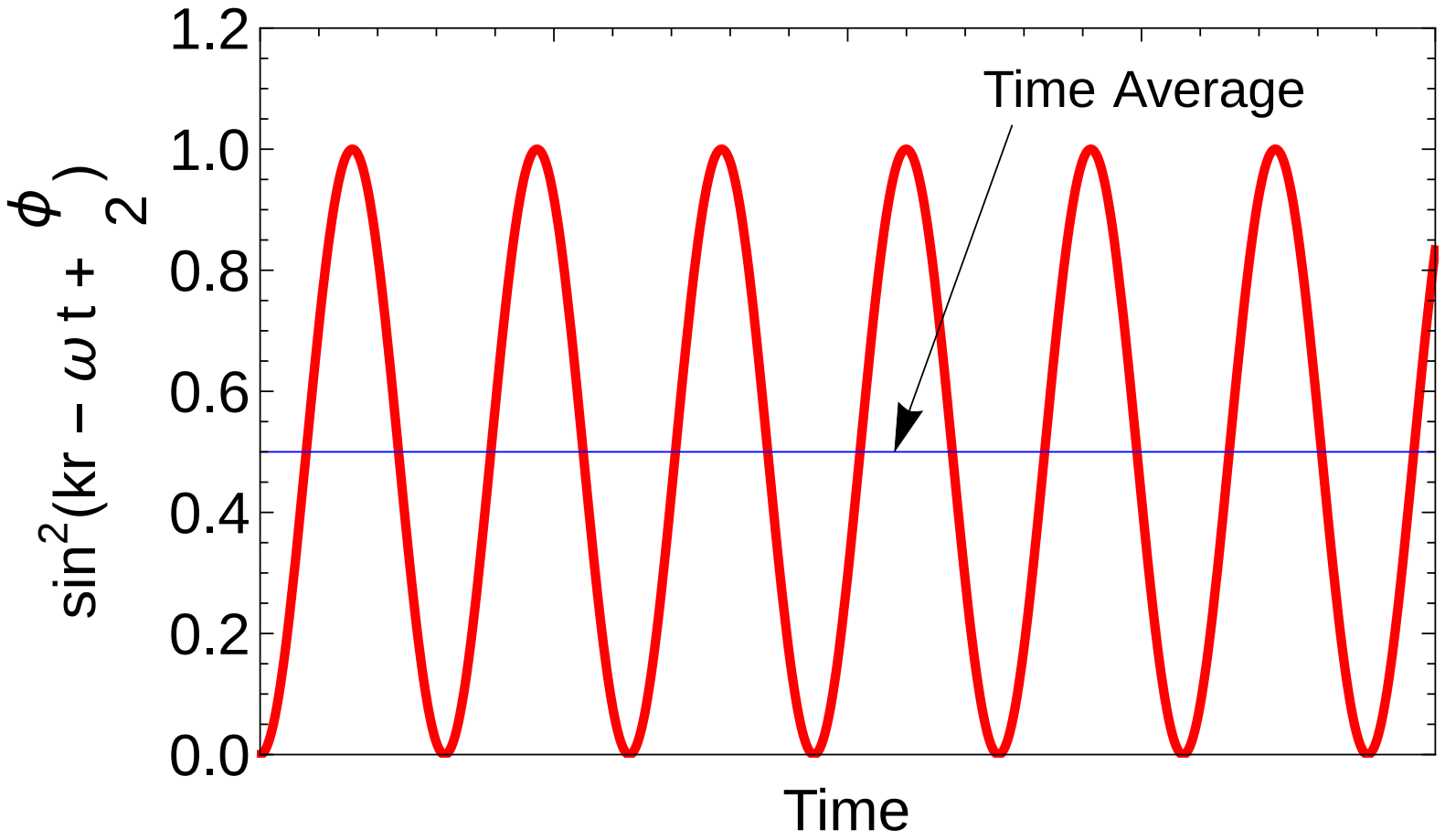
Waves Again 36



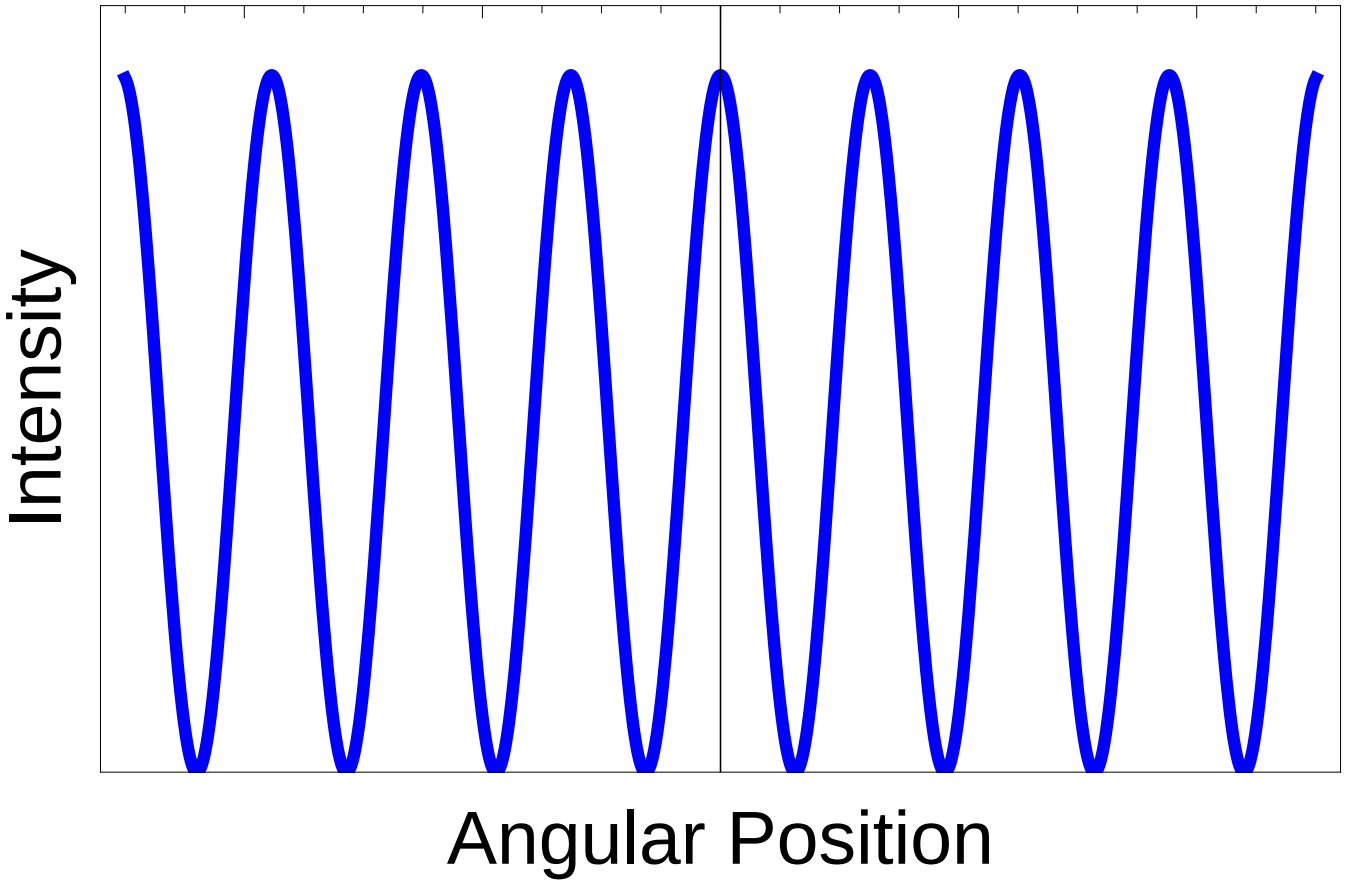
Rapidly Time-Varying Intensity Pattern 37



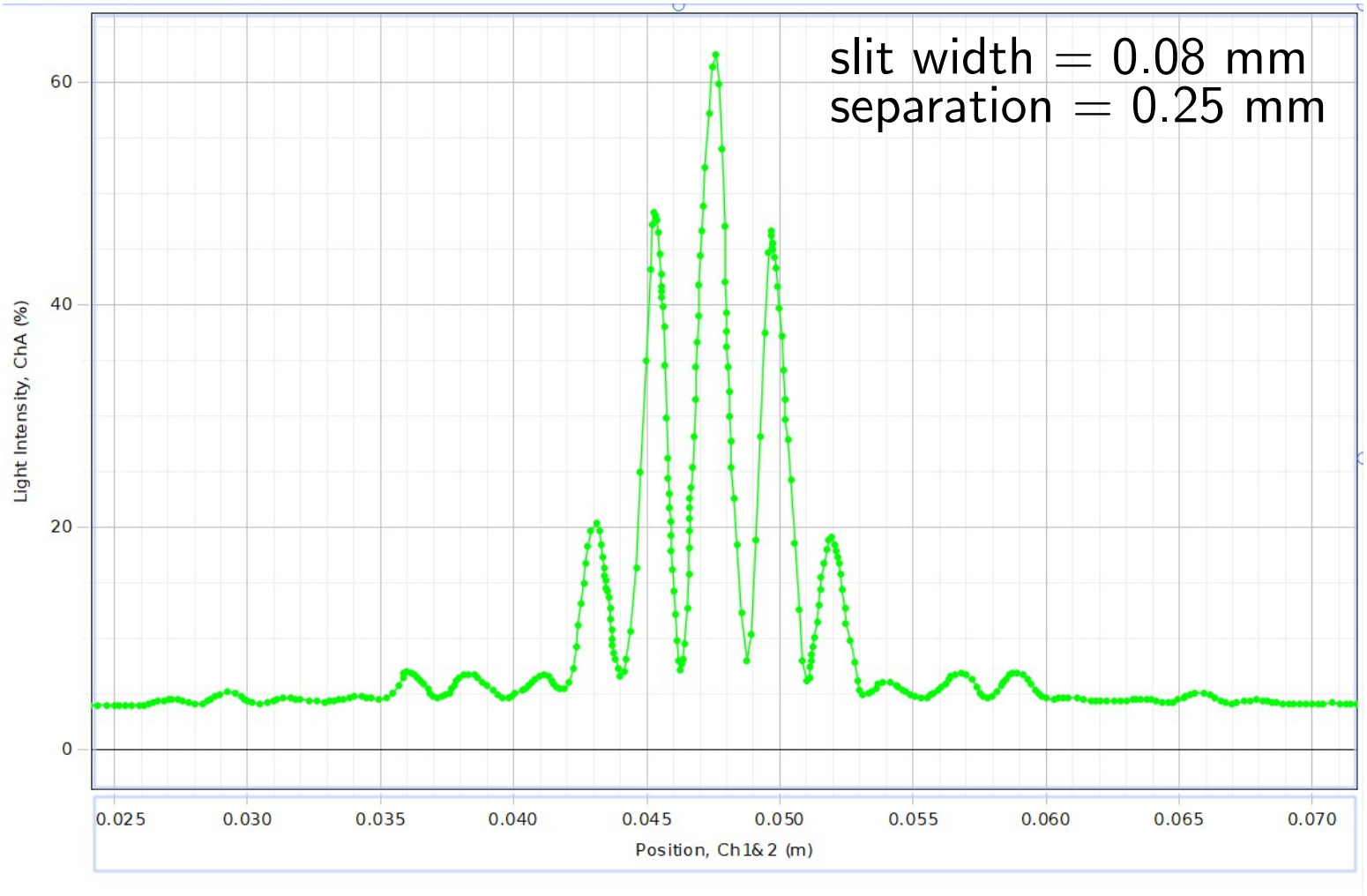
Rapidly Time-Varying Intensity Pattern 38



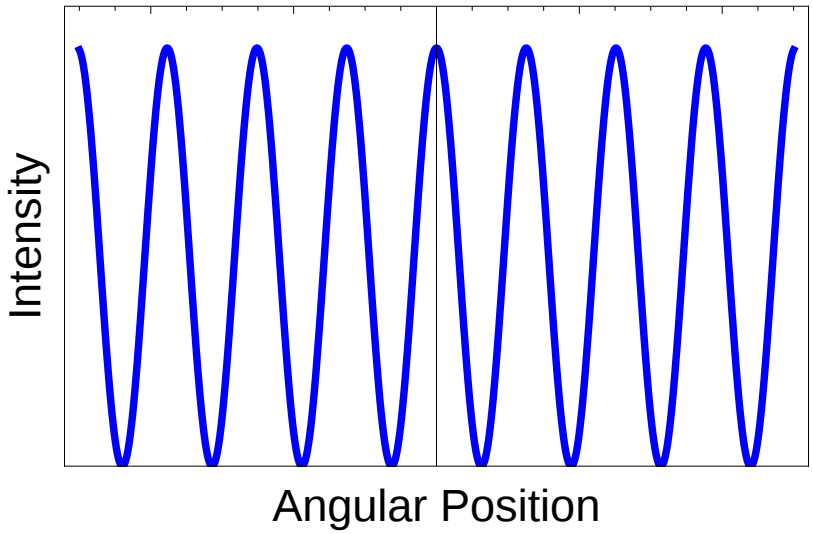
Predicted Double Slit Interference Pattern 39

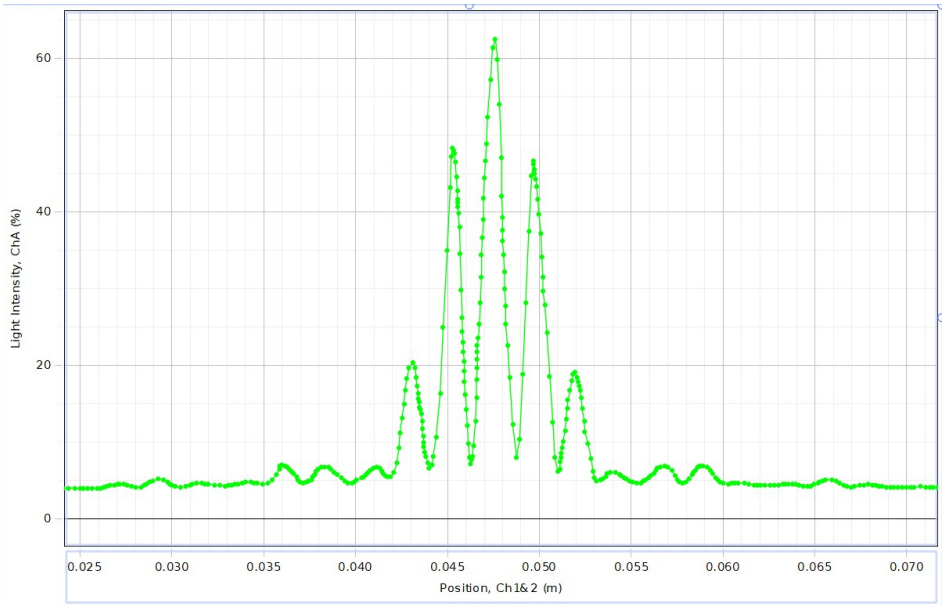


Measured Double Slit Interference Pattern 40



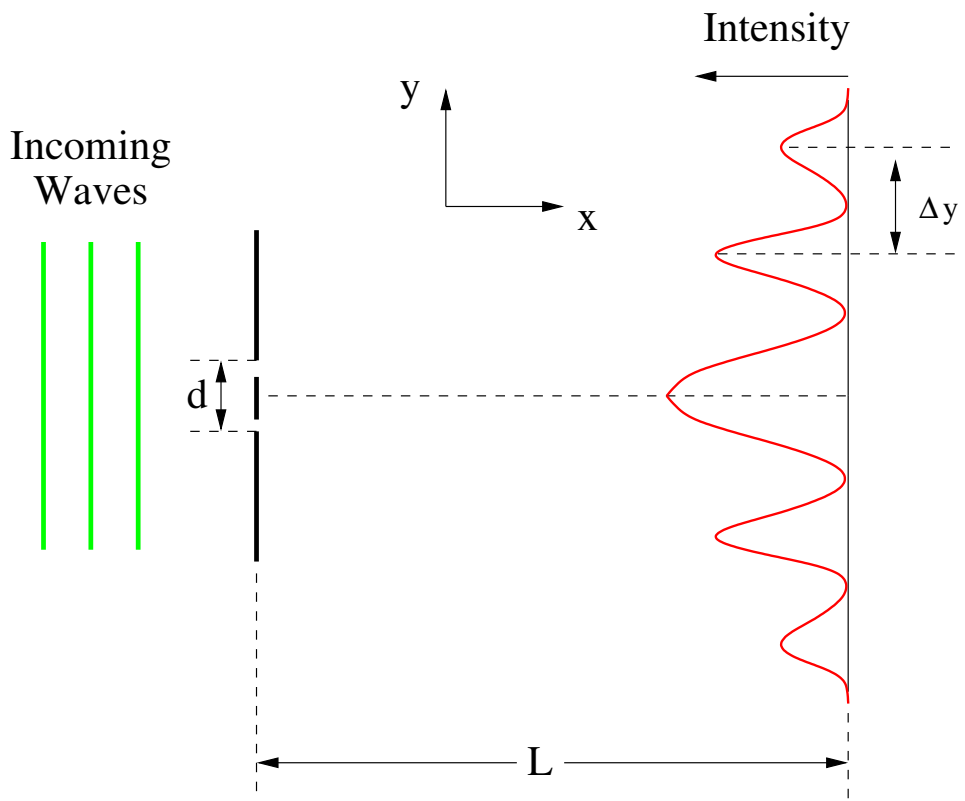
Double Slit Interference Intensity Pattern 41



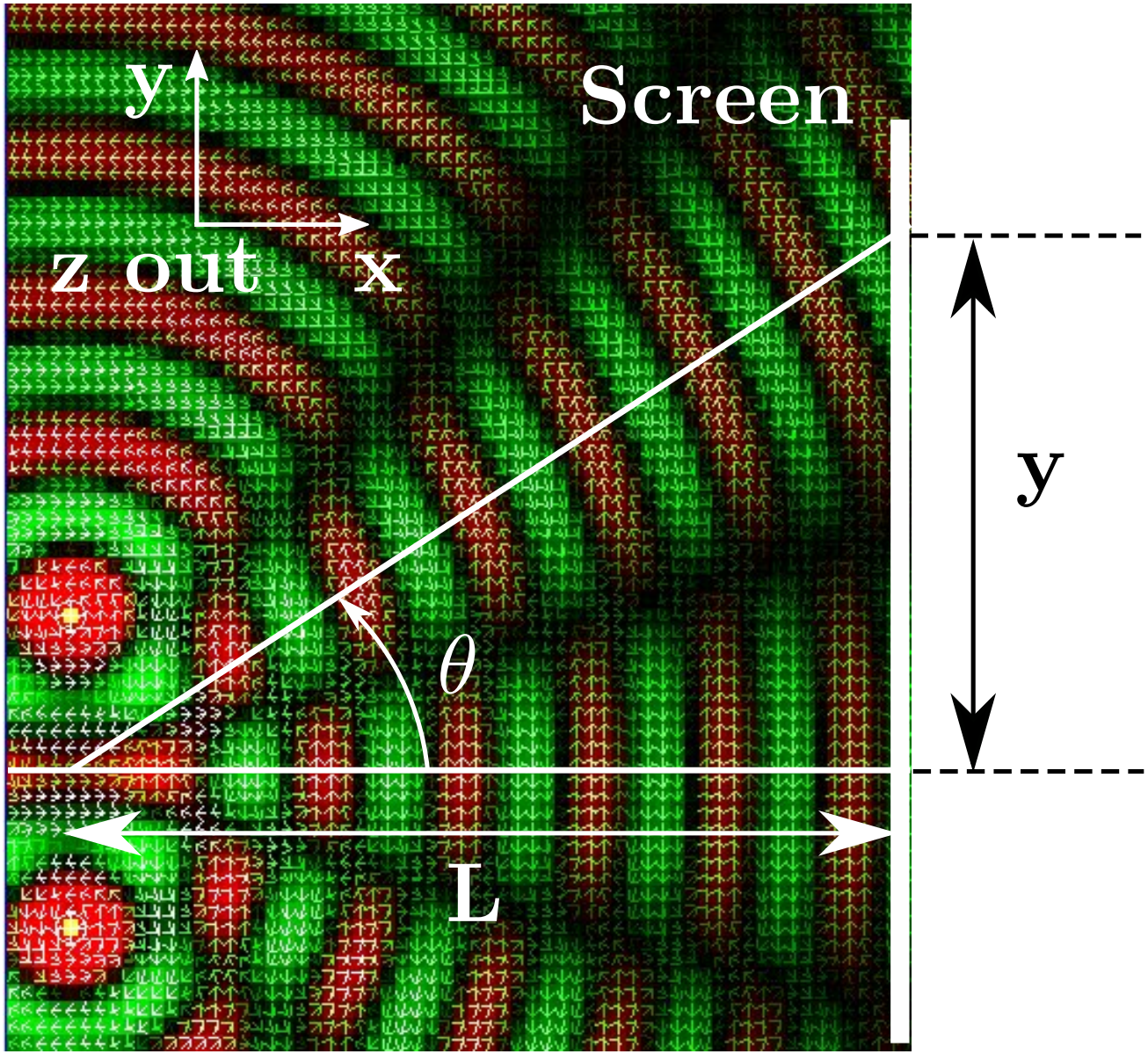


Double Slit Interference 42

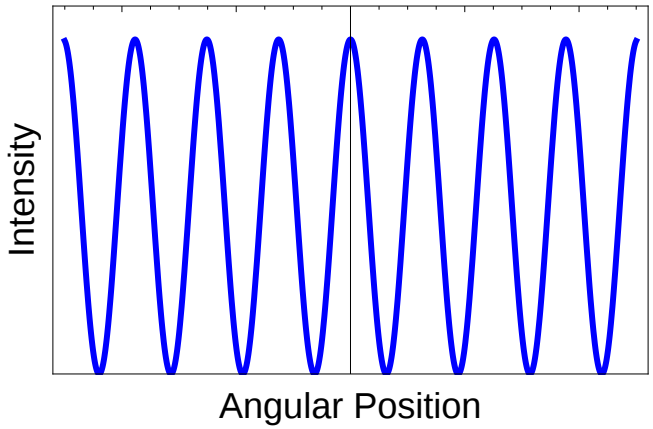
A laser beam is passed through two narrow slits and an interference pattern is thrown on a screen a distance $L = 1.7\ m$ away from the slits. The bright spots are $\Delta y = 0.1\ m$ apart. What is the separation d of the slits? The light has a wavelength $\lambda = 6.5 \times 10^{-7}\ m$.



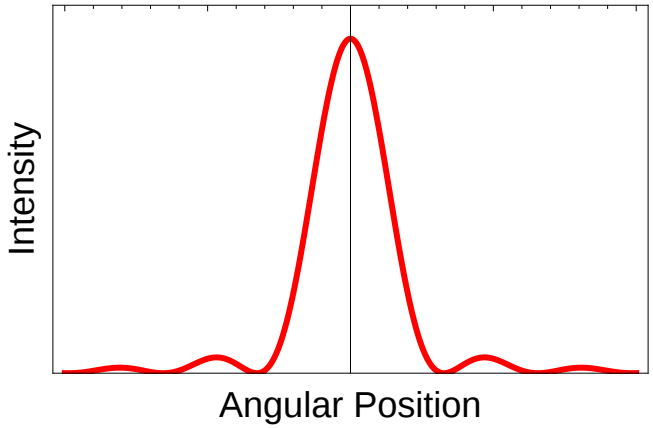
Double Slit Interference Geometry 43

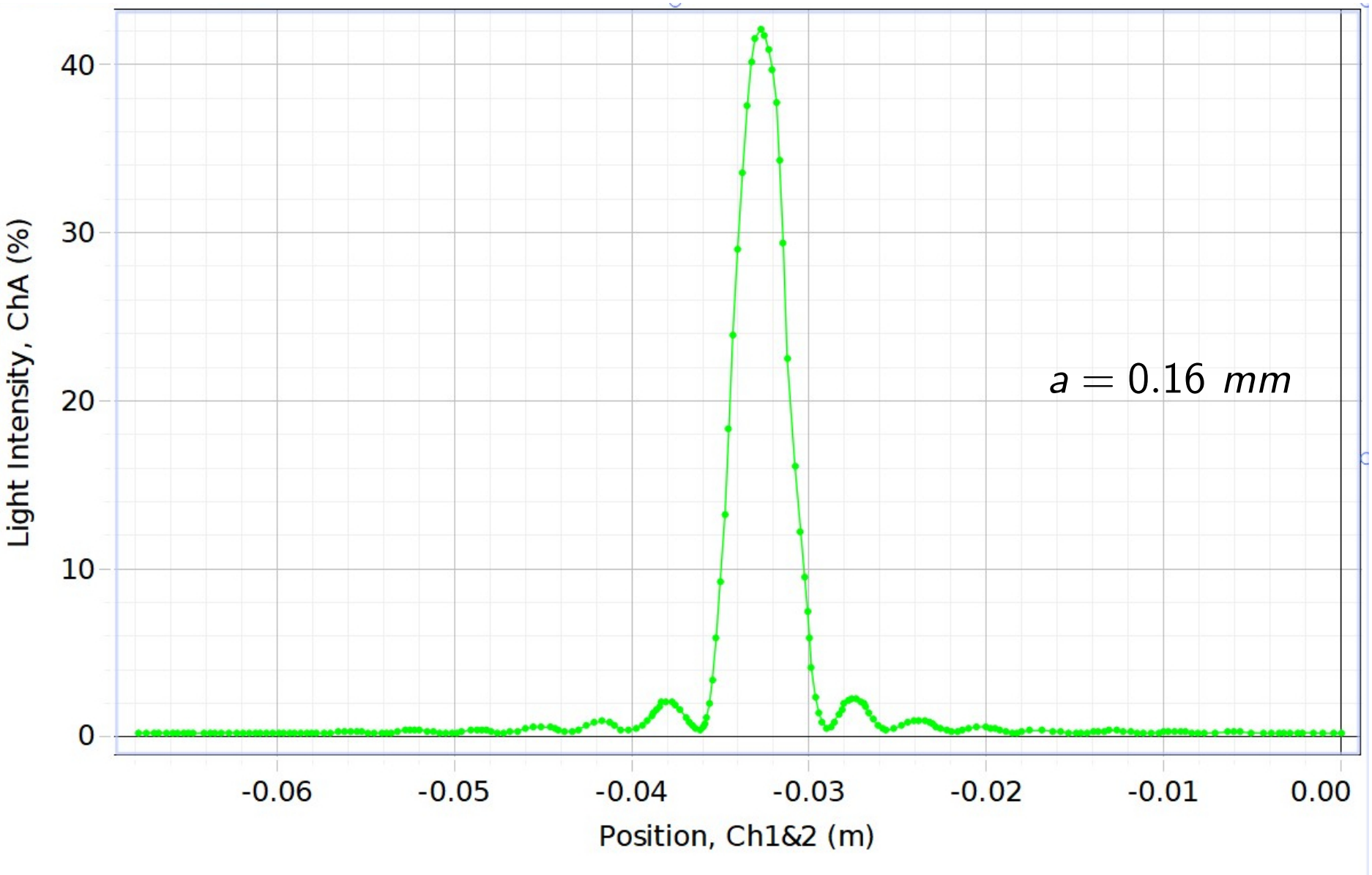


Interference

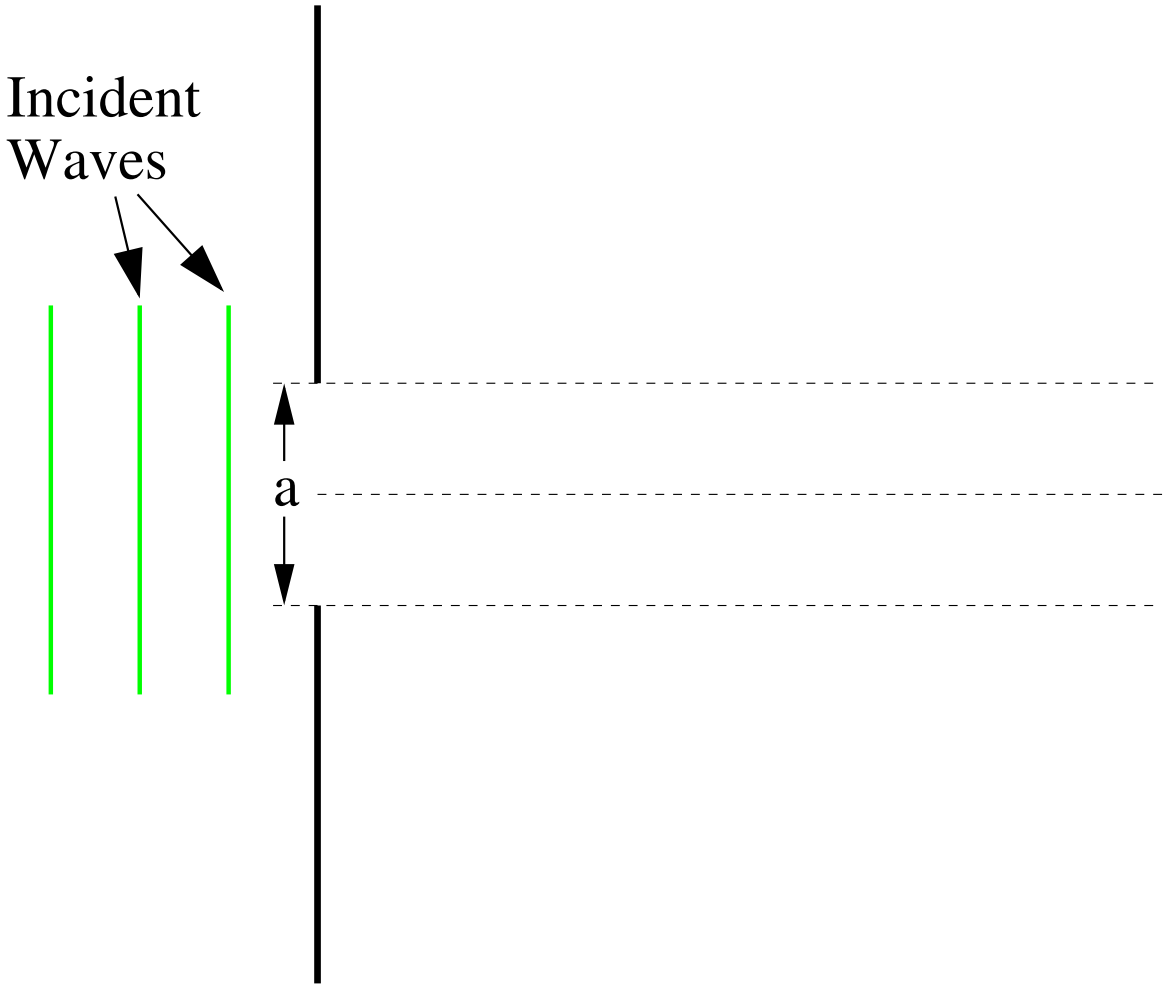


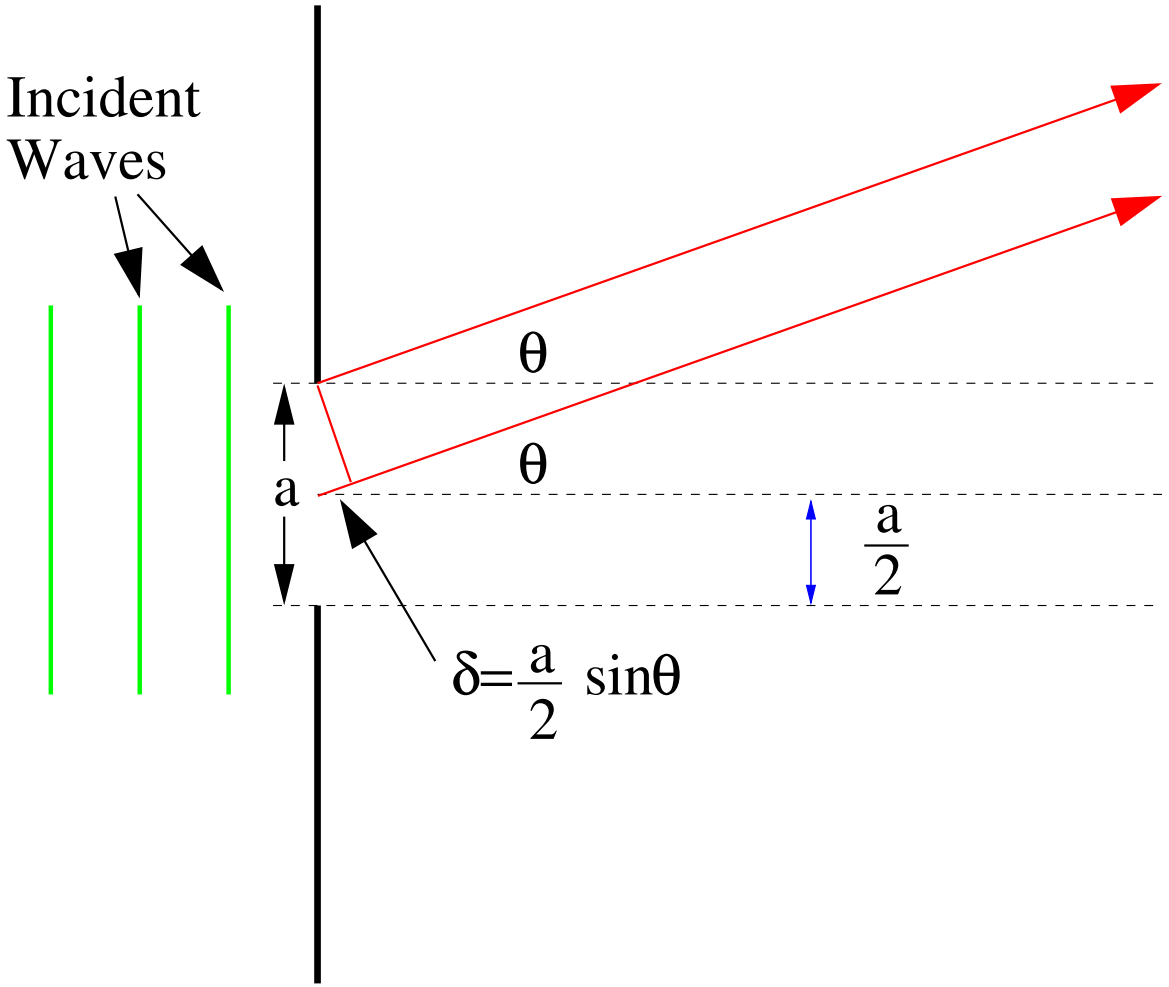
Diffraction

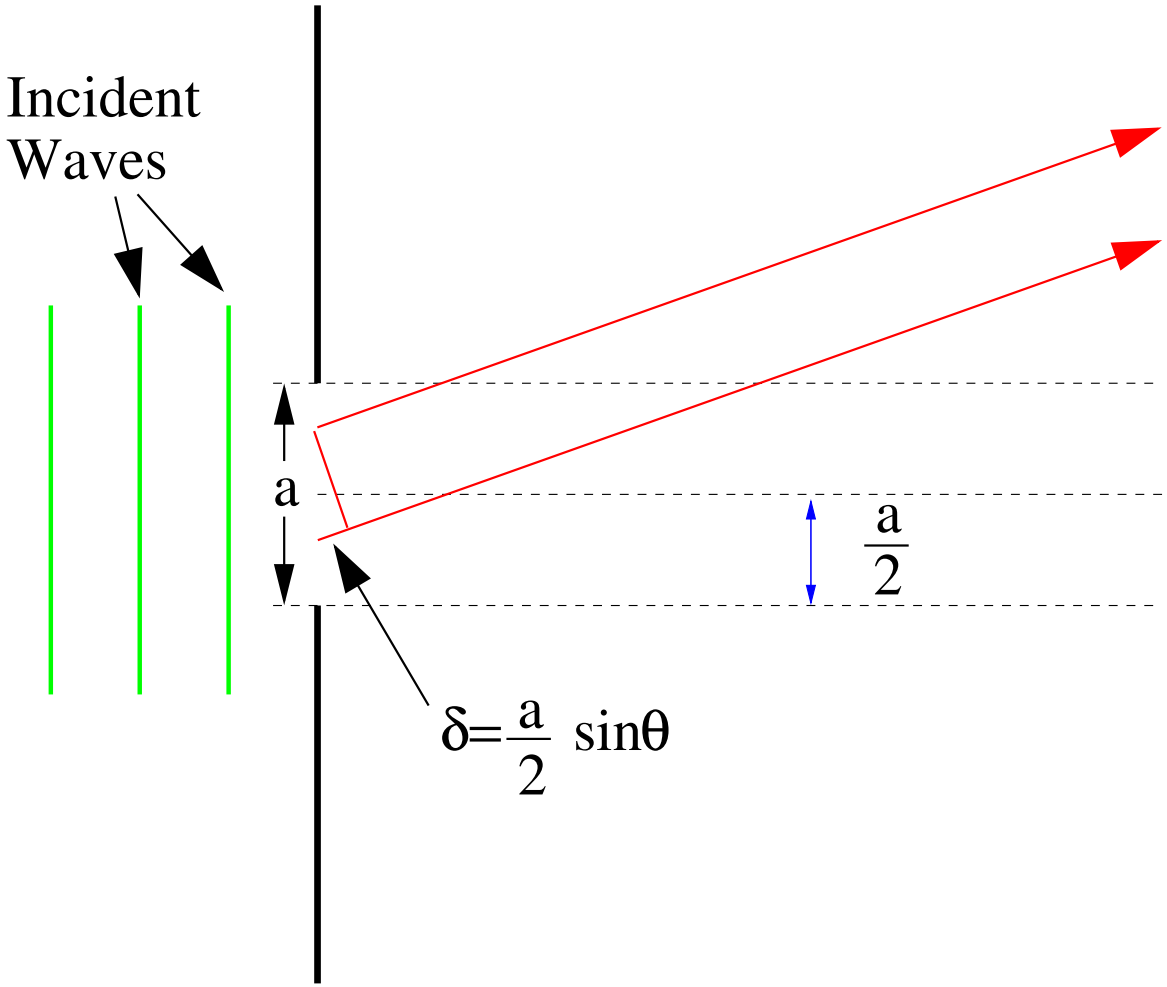


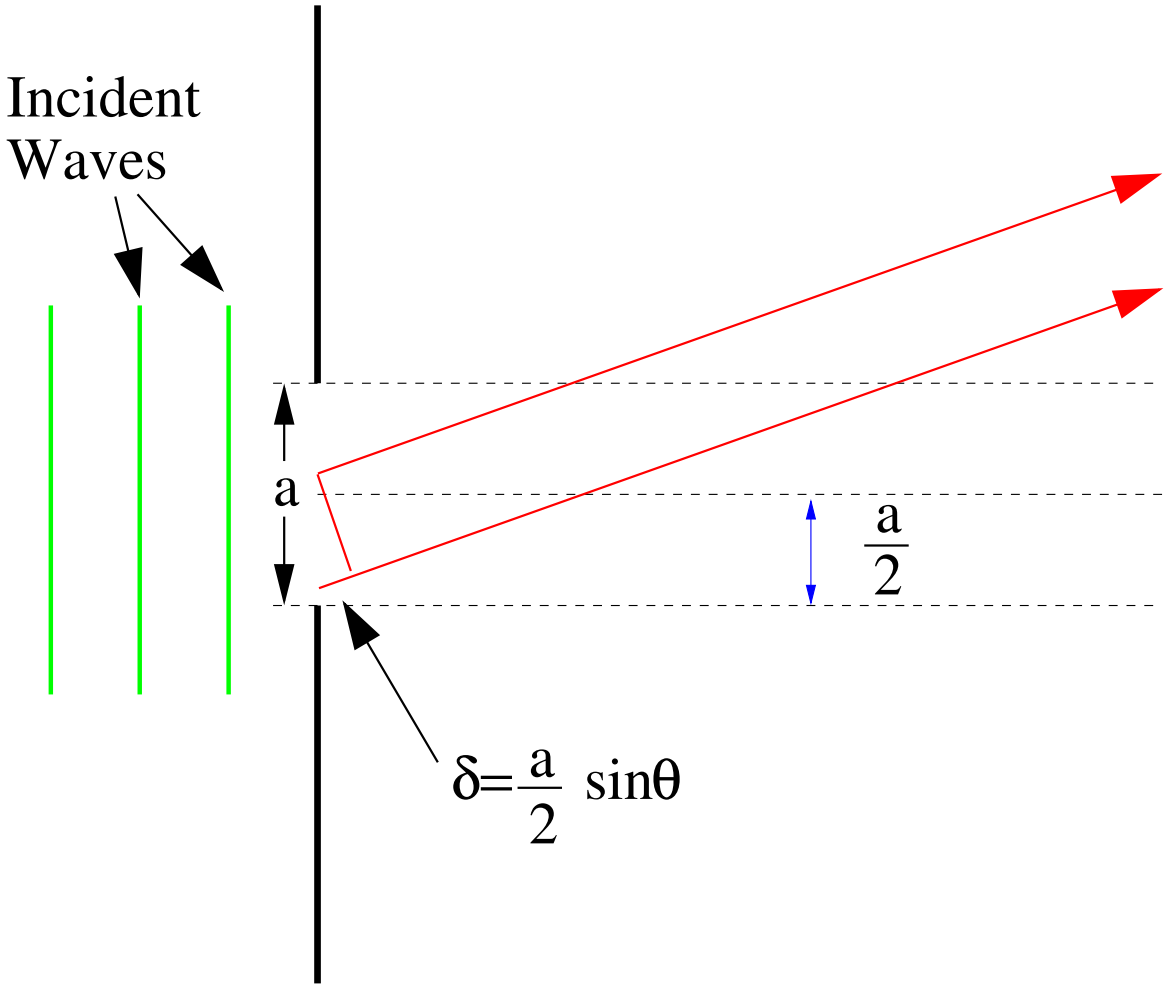

40
30
20
10
0
Light Intensity, ChA (%)
-0.06
-0.05
-0.04
-0.03
-0.02
-0.01
0.00
Position, Ch1&2 (m)
$a = 0.16\ mm$

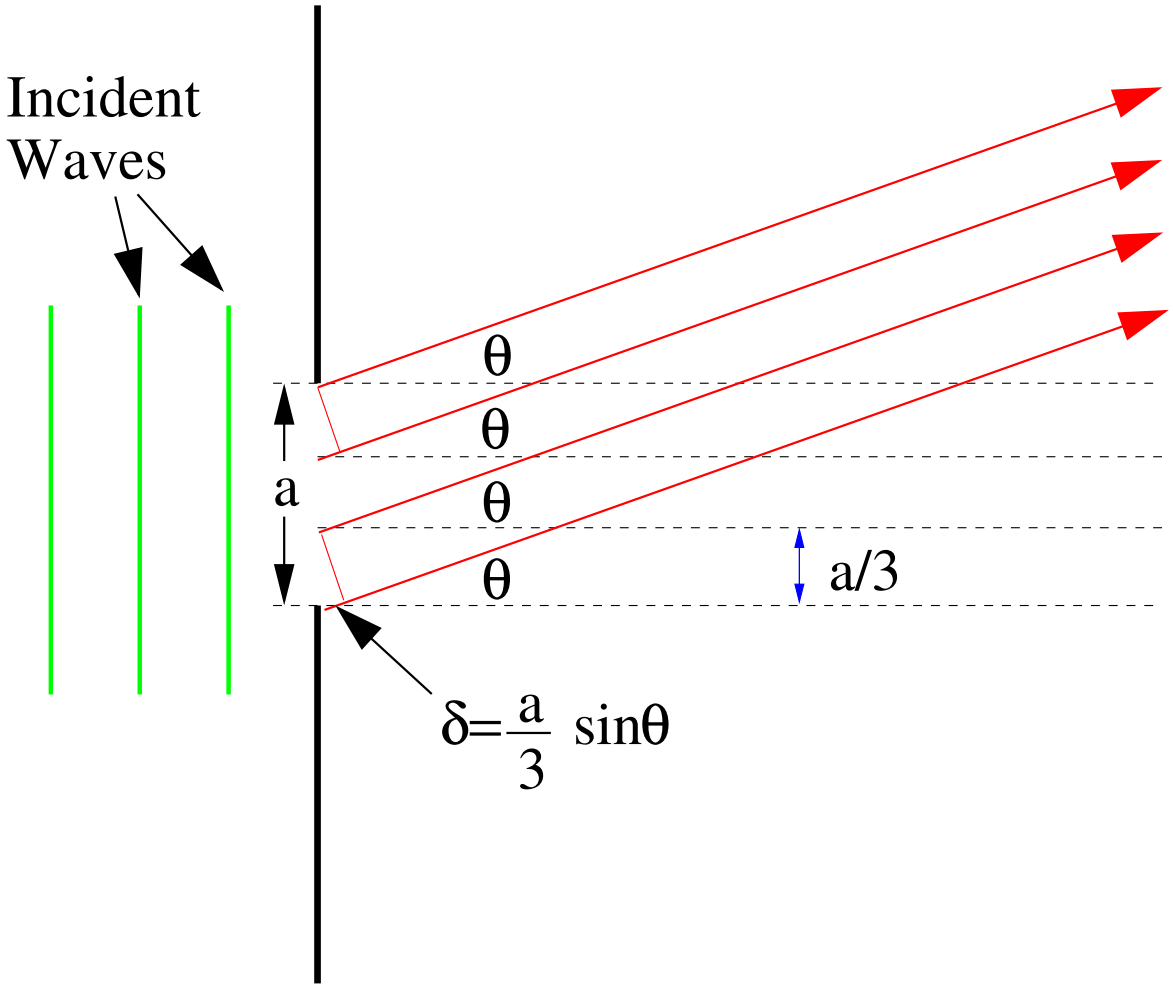
Diffraction 46

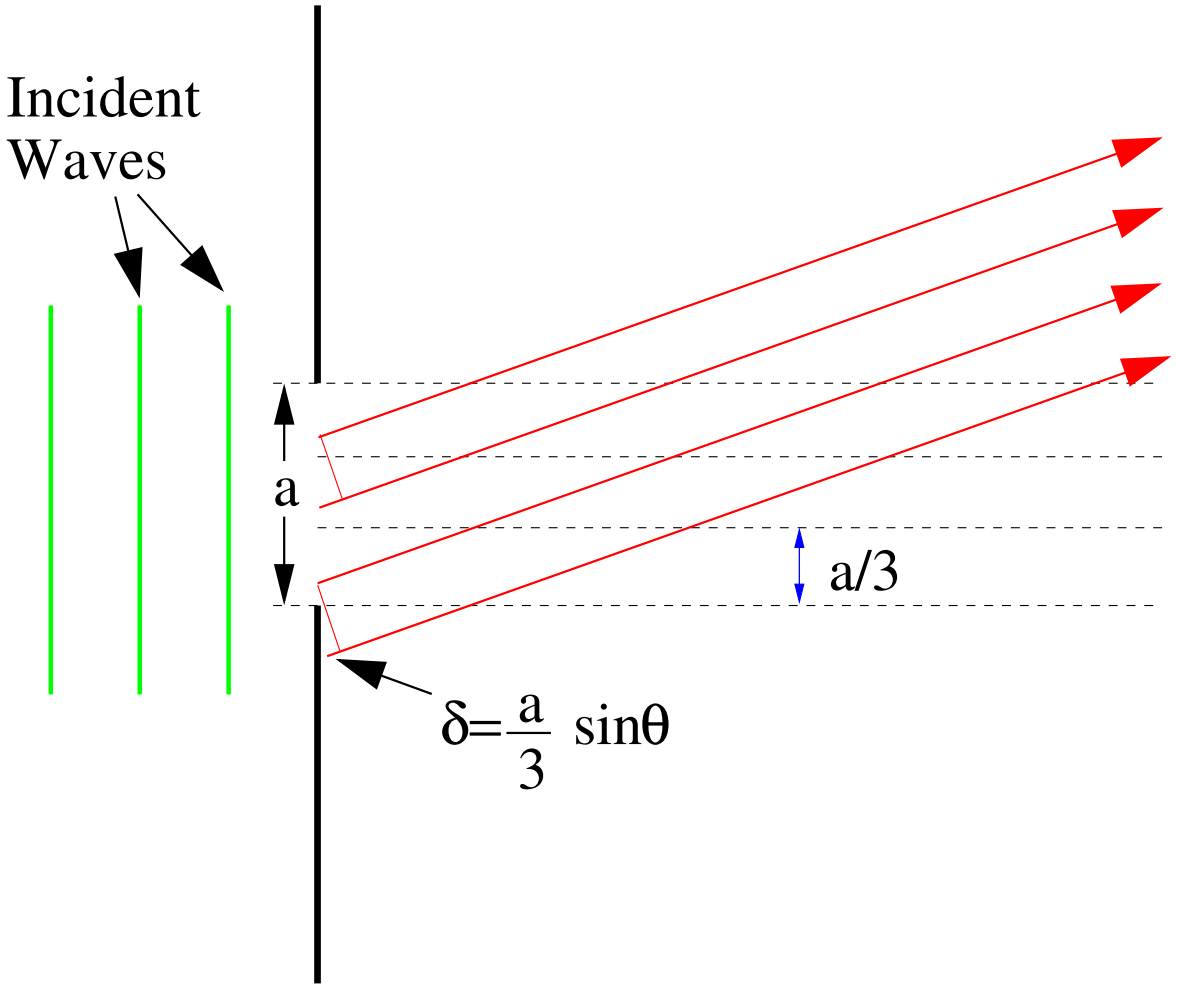


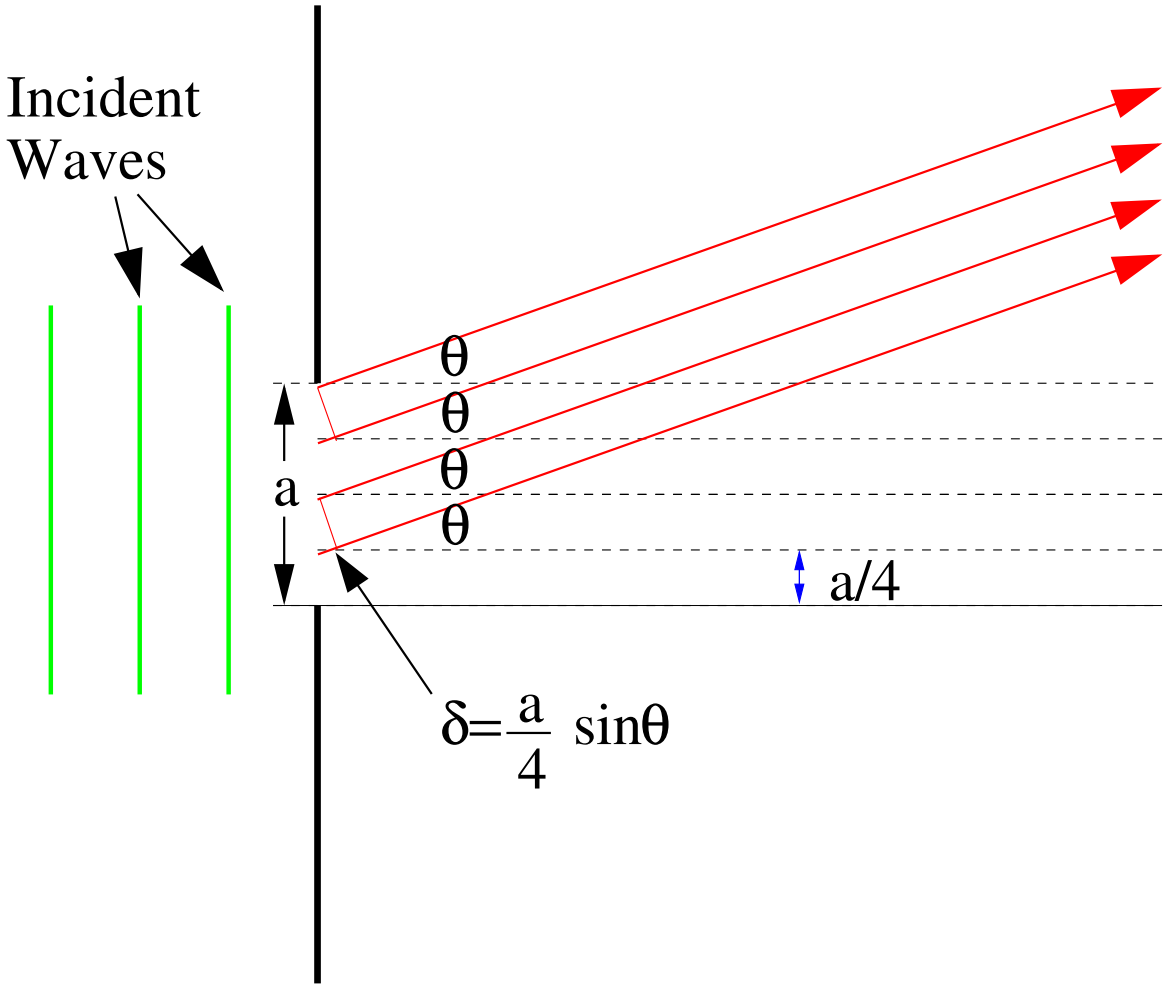

Incident
Waves
θ
θ
a
a
2
δ=
a
2
sinθ

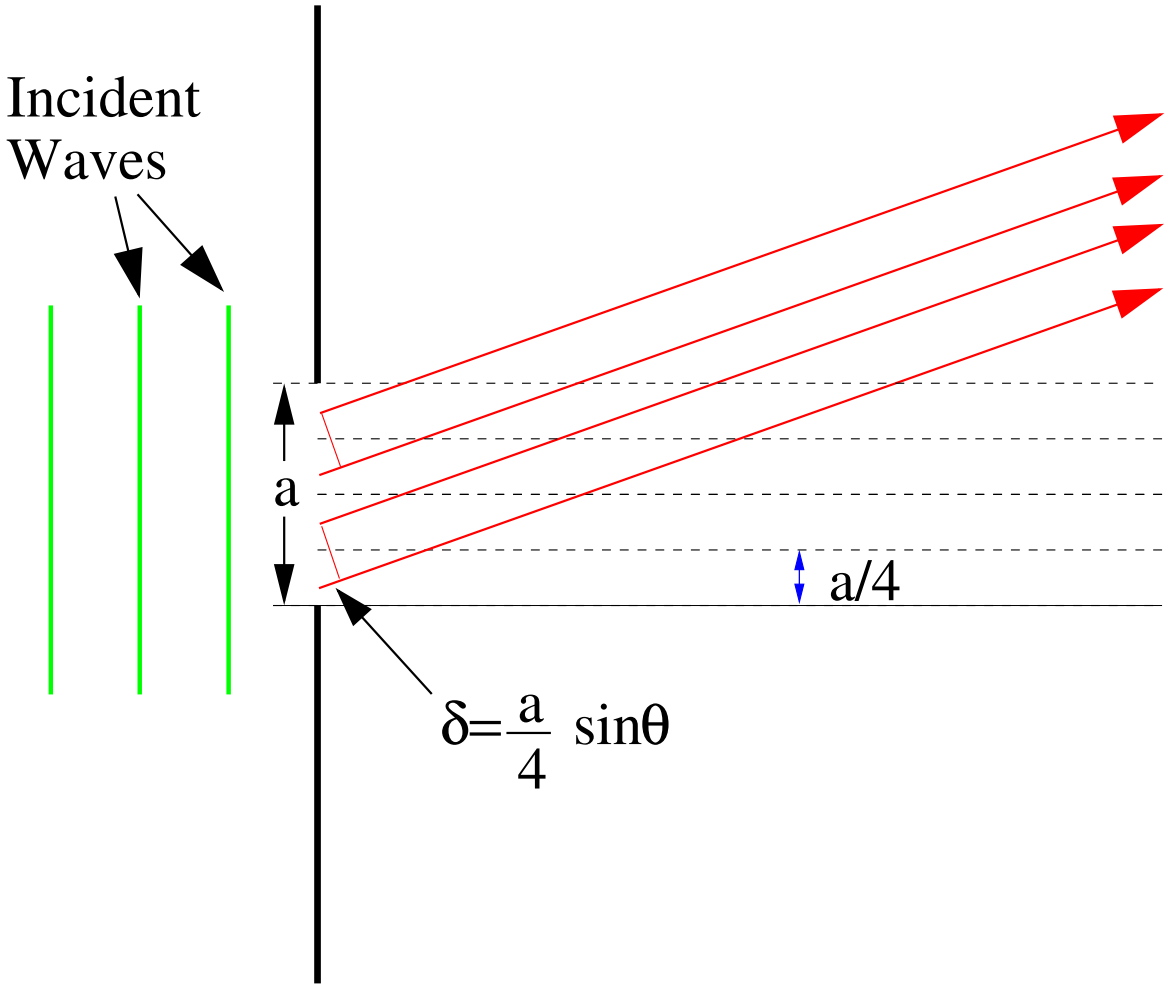

Incident
Waves
a
a/2
δ=a/2 sinθ


Incident
Waves
a
a/2
δ=a/2 sinθ


Incident
Waves
θ
θ
θ
θ
a
a/3
δ=a/3 sinθ

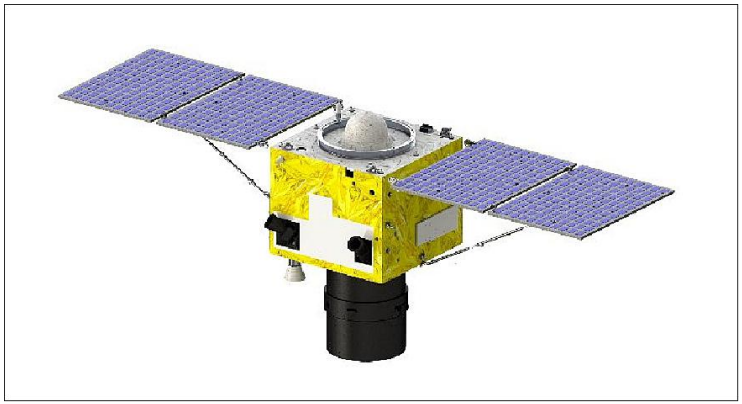

Incident
Waves
a
a/3
δ=a/3 sinθ


Incident
Waves
θ
θ
θ
θ
a
a/4
δ=a/4 sinθ


Incident
Waves
a
a/4
δ=a/4 sinθ

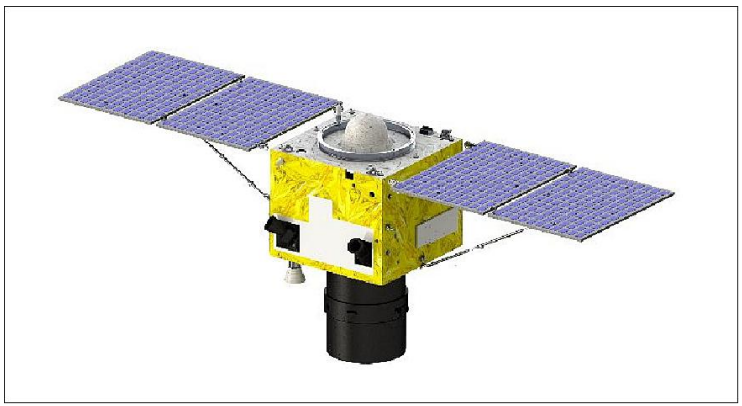
The Limits of Sight 54

The SuperView 1B satellite is a commercial satellite designed to take surveillance photographs for sale and has been active since 2016. The cost for photos from the satellite archive is as low \$14. The aperture of the camera on the satellite is $a = 0.42\ m$ and the satellite operates $L = 530\ km$ above the Earth. What is the size of the smallest object visible to the camera? Visible light covers a range of wavelengths of $\lambda \approx 400 - 700\ nm$. What is the size of the smallest object visible to human eyes?

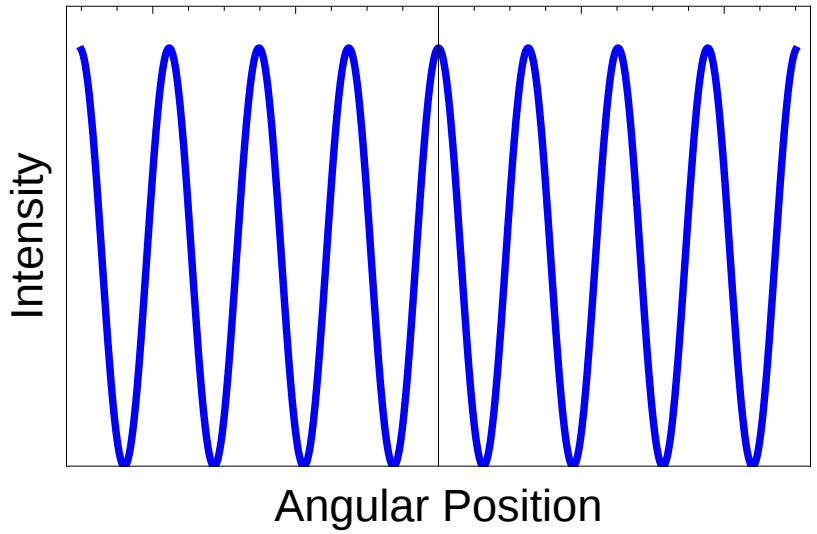


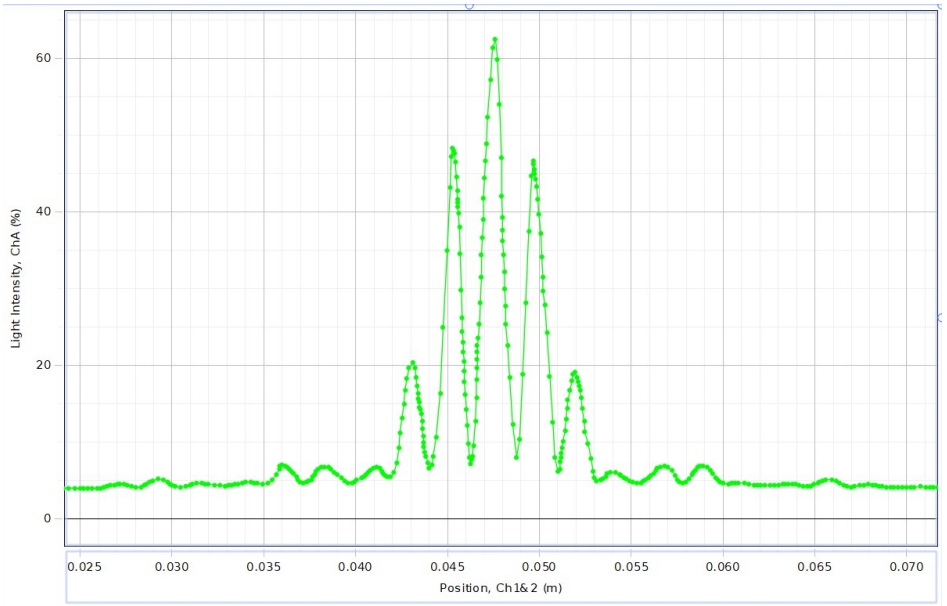
The Limits of Sight 55

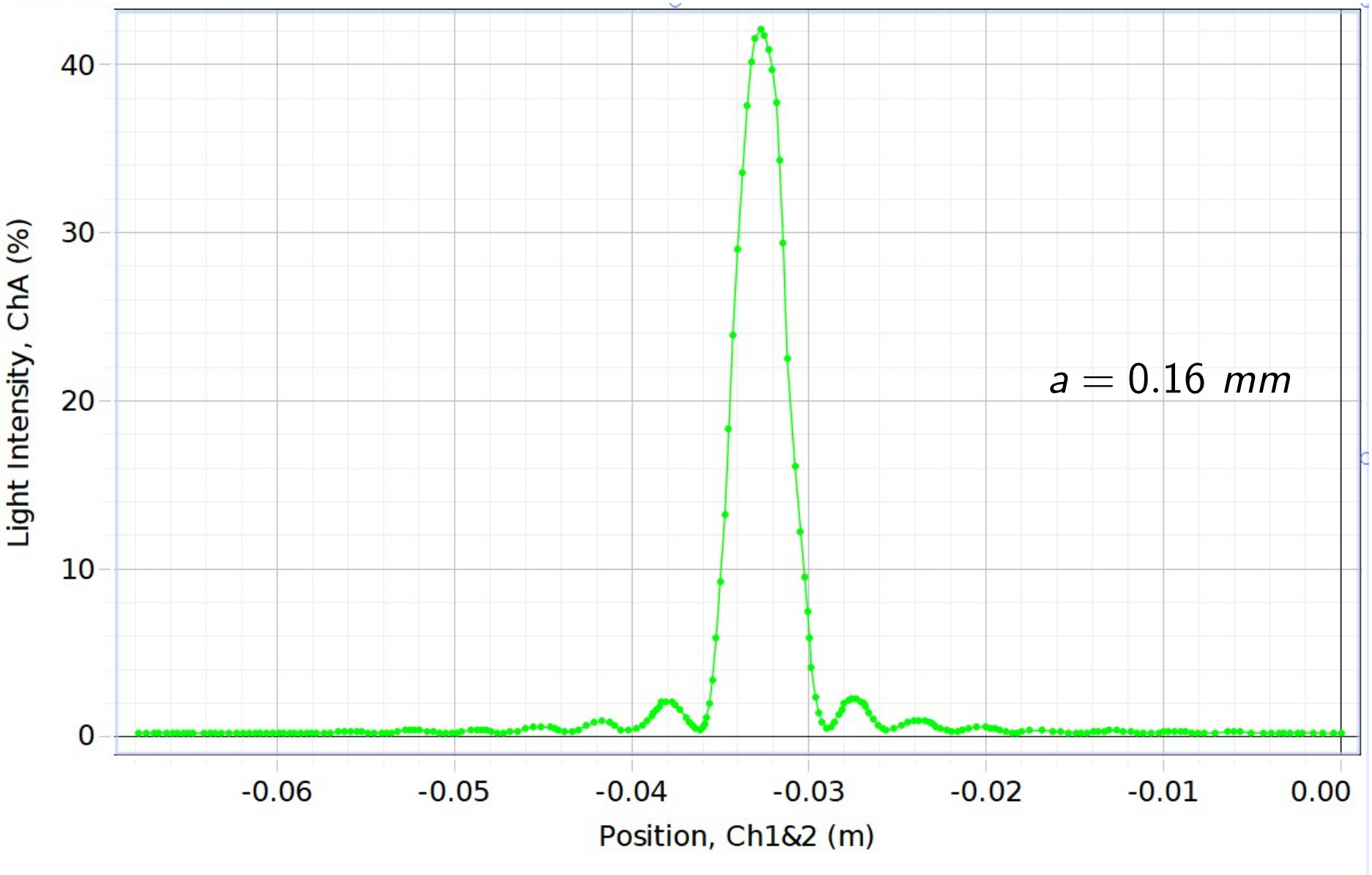
cial satellite designed to take
been active since 2016. The cost
low $14. The aperture of the
d the satellite operates
ıe size of the smallest object
s a range of wavelengths of
he smallest object visible to



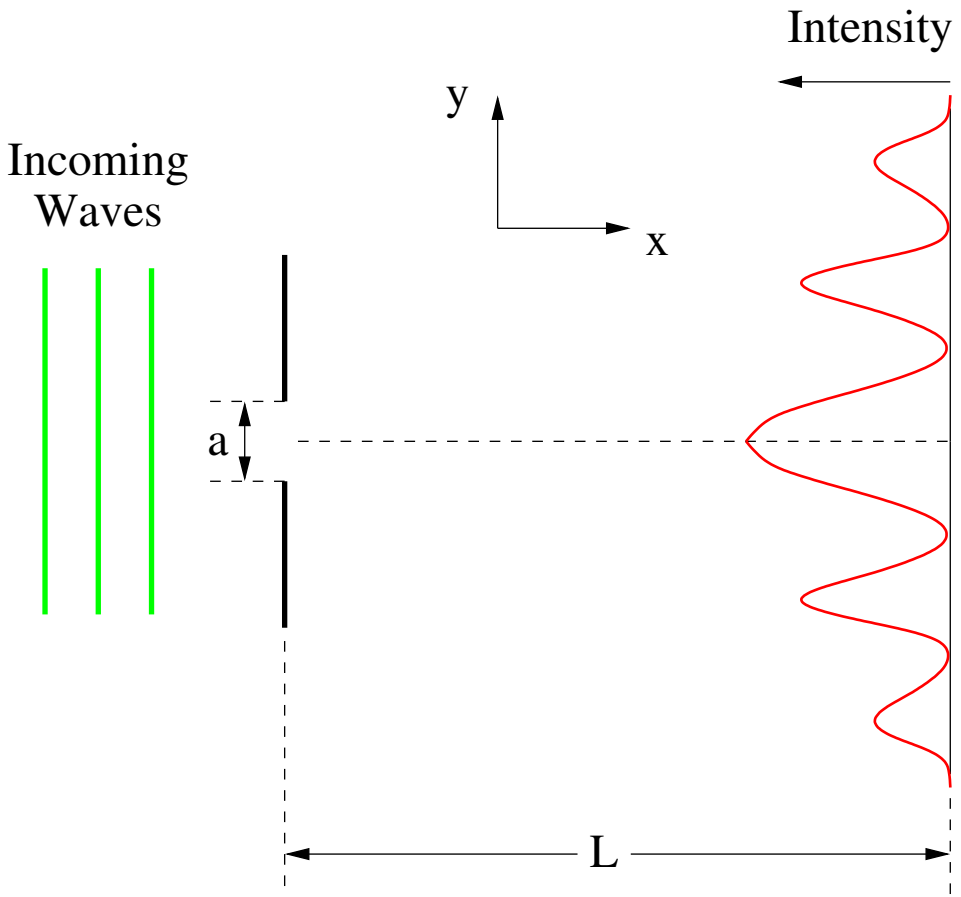
Double Slit Interference Intensity Pattern 56





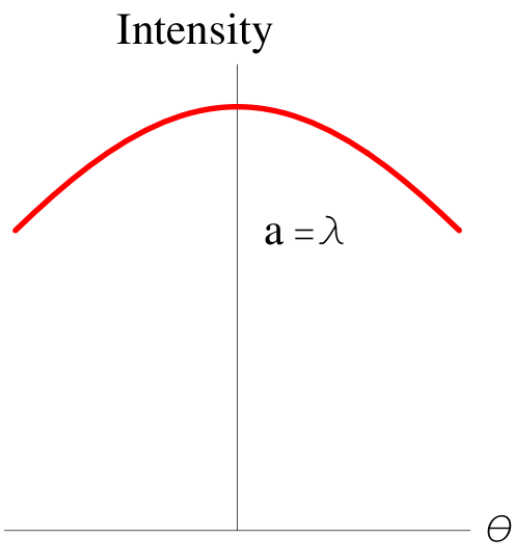

40
30
20
10
0
Light Intensity, ChA (%)
-0.06
-0.05
-0.04
-0.03
-0.02
-0.01
0.00
Position, Ch1&2 (m)
$a = 0.16\ mm$

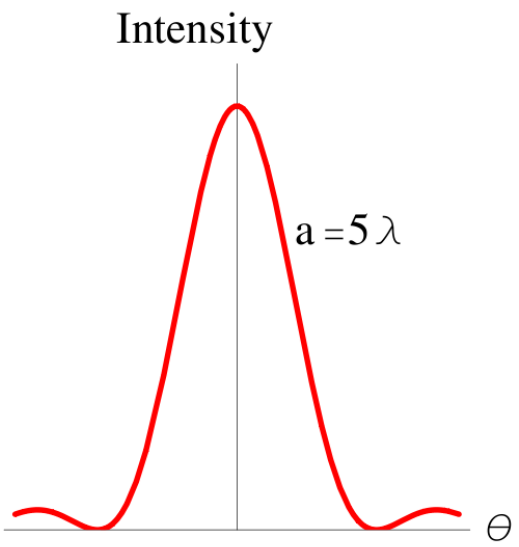
A laser beam of wavelength $\lambda = 6328$ Å is shone on a single slit of width $a = 1.0$ *mm*. If a screen is placed a distance $L = 0.40$ *m* away, then how far from the central maximum is the first dark spot on each side of the central maximum? What is the angular size of the central peak?

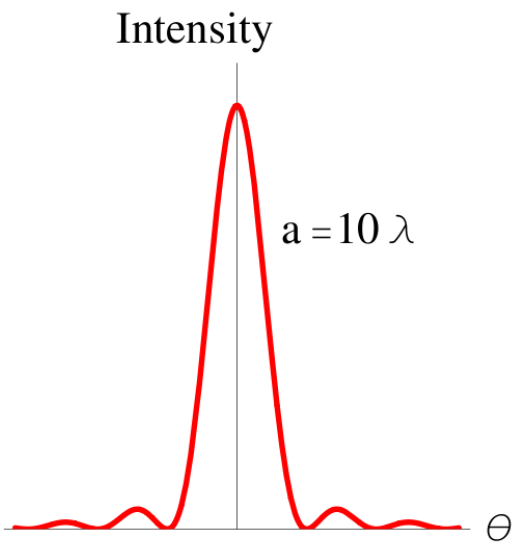


$$I = I_m \left(\frac{\sin \alpha}{\alpha} \right)^2 = I_m \left(\frac{\sin \left(\frac{\pi a}{\lambda} \sin \theta \right)}{\frac{\pi a}{\lambda} \sin \theta} \right)^2$$

$$\alpha = \frac{\pi a}{\lambda} \sin \theta \qquad \theta \equiv \text{a} \textit{ngular position}$$







If

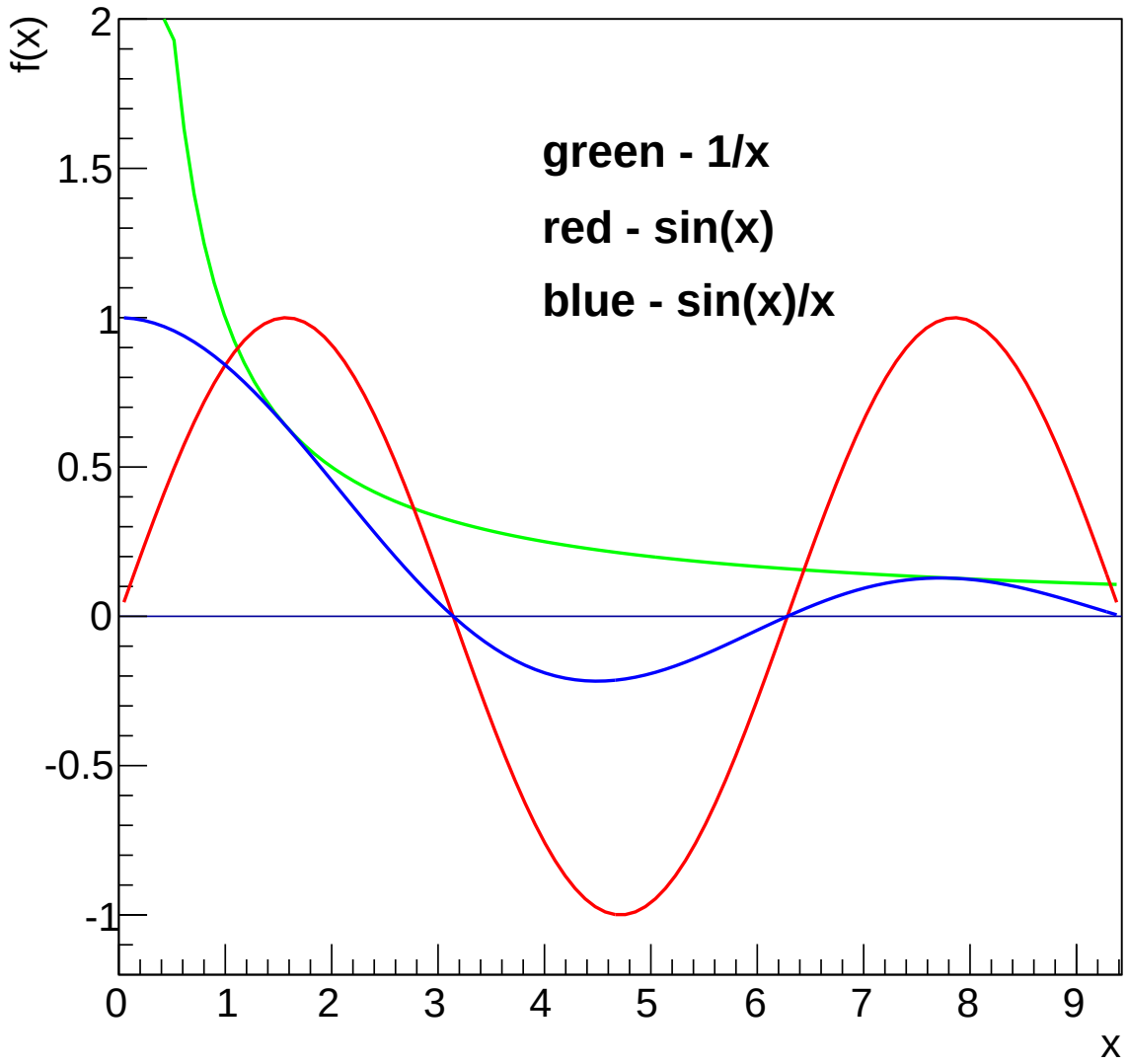
$$f(a) = g(a) = 0$$

and

$$\lim_{x \to a^+} \frac{f'(x)}{g'(x)} = A$$

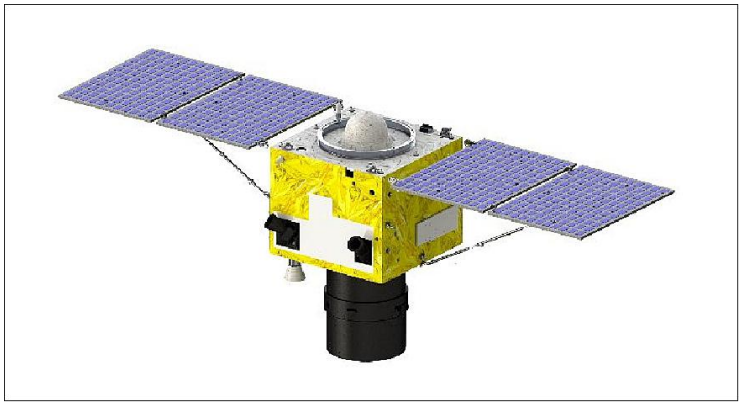
then

$$\lim_{x \to a^+} \frac{f(x)}{g(x)} = A$$


f(x)
2
1.5
1
0.5
0
-0.5
-1
0
1
2
3
4
5
6
7
8
9
x
green - 1/x
red - sin(x)
blue - sin(x)/x

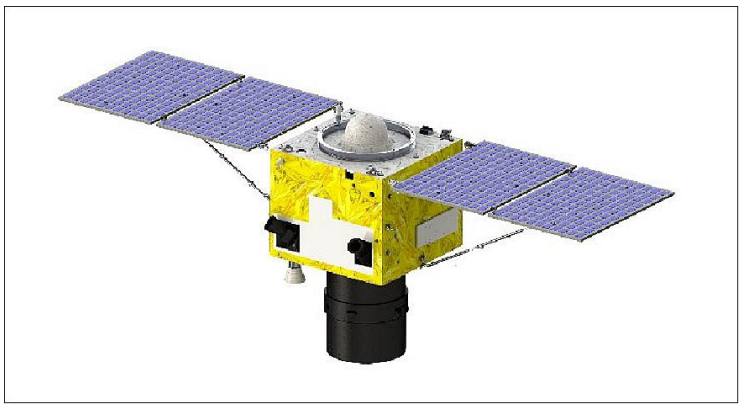
The Limits of Sight 62

The SuperView 1B satellite is a commercial satellite designed to take surveillance photographs for sale and has been active since 2016. The cost for photos from the satellite archive is as low \$14. The aperture of the camera on the satellite is $a = 0.42\ m$ and the satellite operates $L = 530\ km$ above the Earth. What is the size of the smallest object visible to the camera? Visible light covers a range of wavelengths of $\lambda \approx 400 - 700\ nm$. What is the size of the smallest object visible to human eyes?

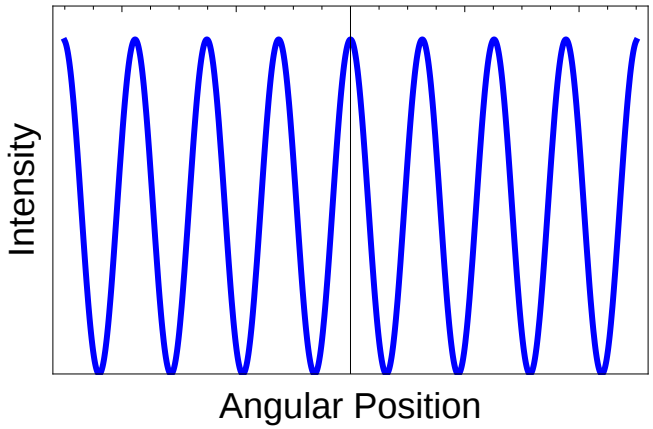


The Limits of Sight 63

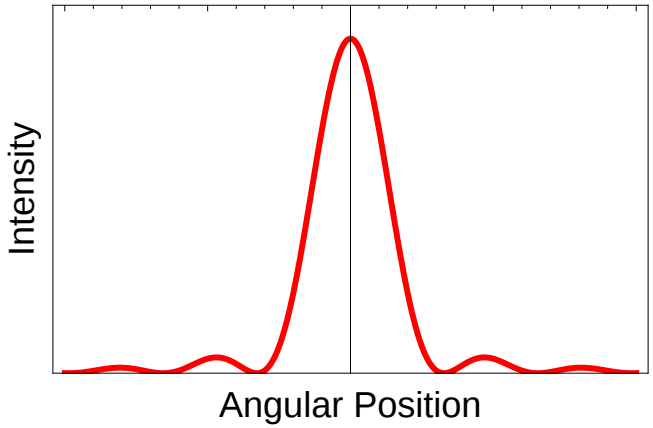
cial satellite designed to take
been active since 2016. The cost
low $14. The aperture of the
d the satellite operates
ıe size of the smallest object
s a range of wavelengths of
he smallest object visible to

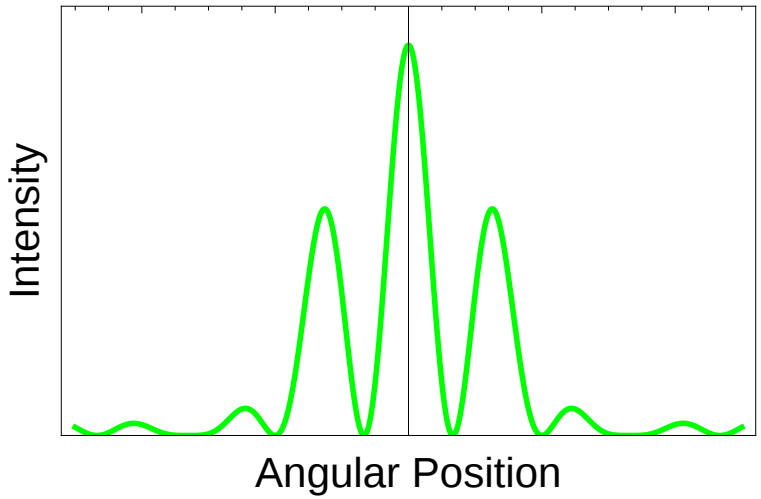


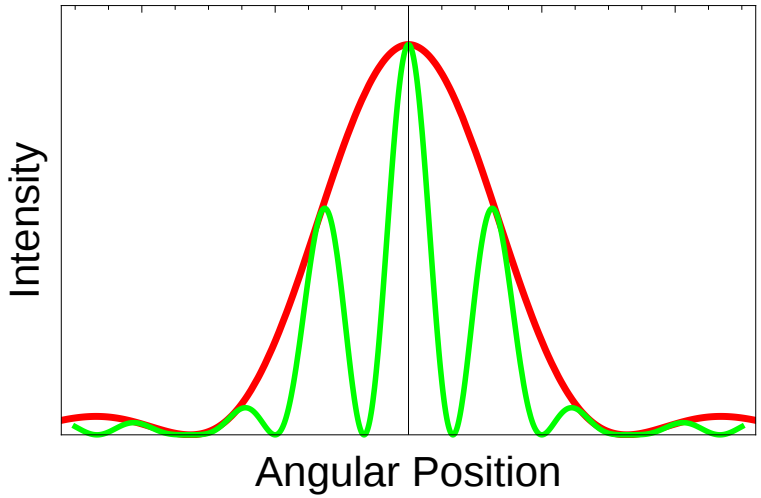
Interference



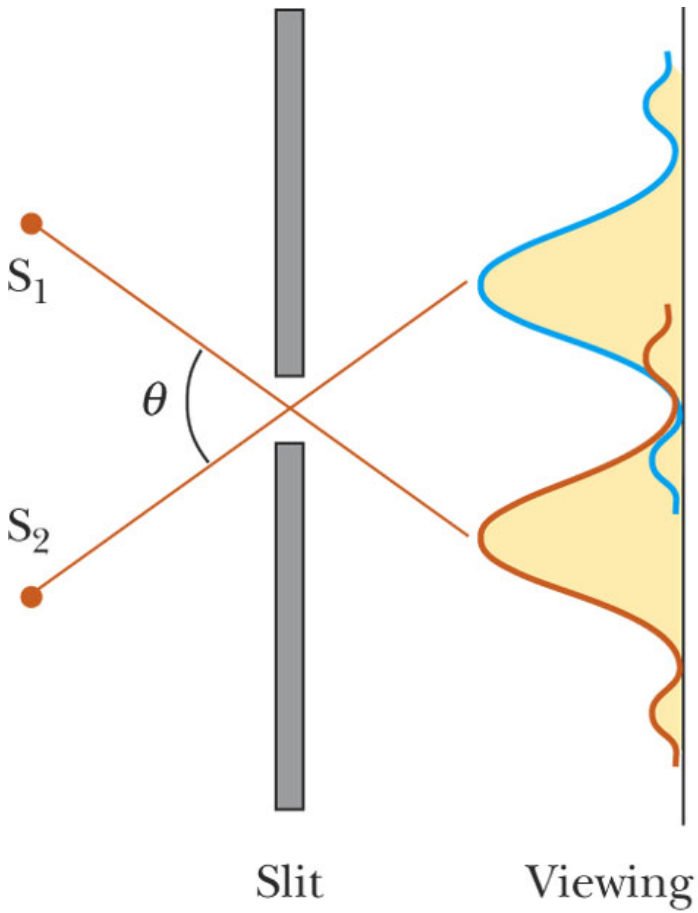
Diffraction

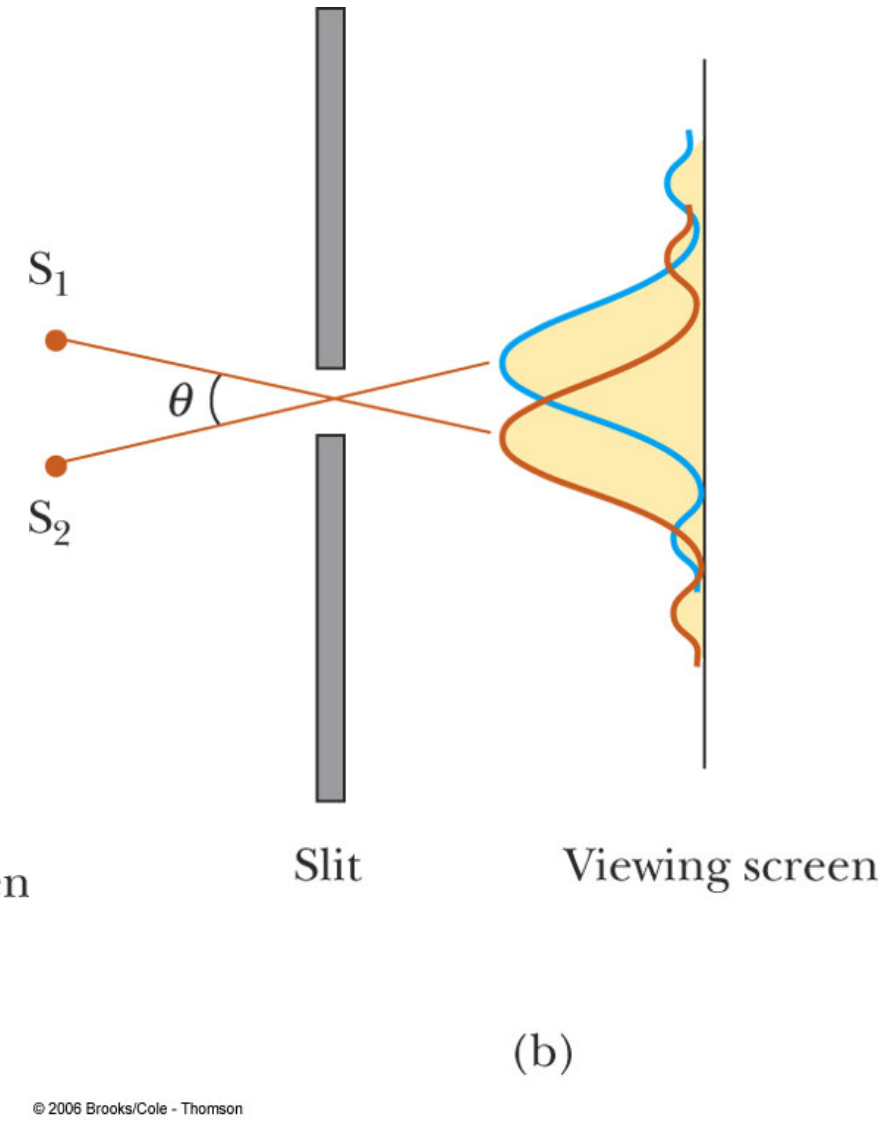



Intensity
Angular Position


Intensity
Angular Position

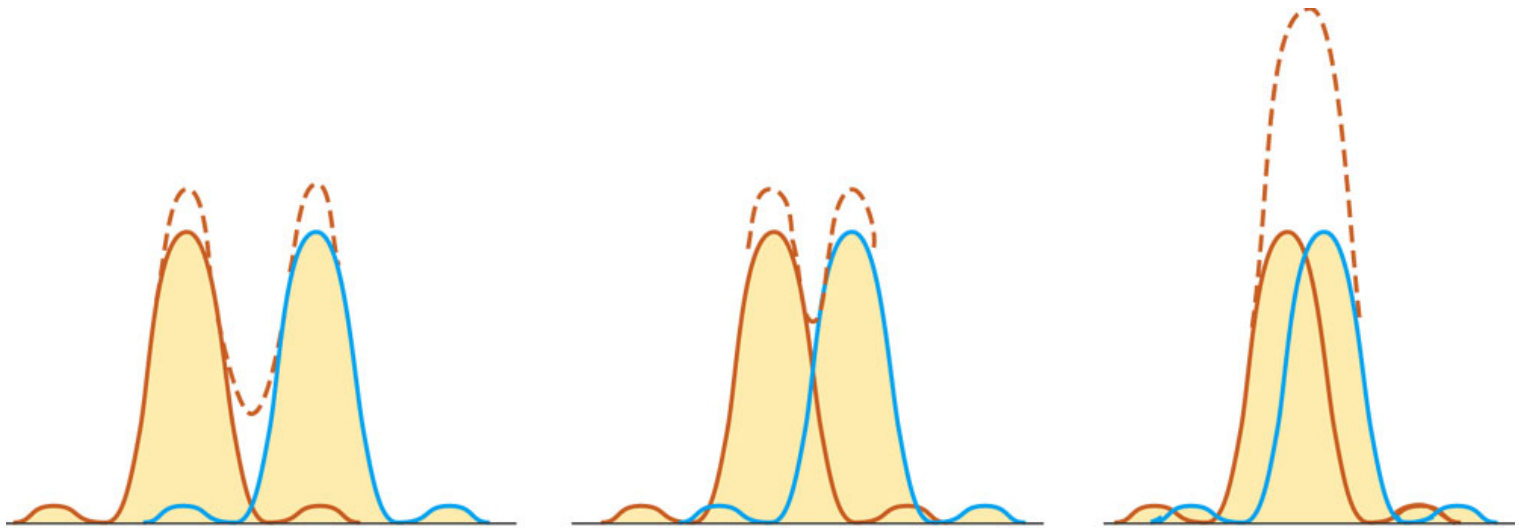
Defining the Limits of Sight-1 66





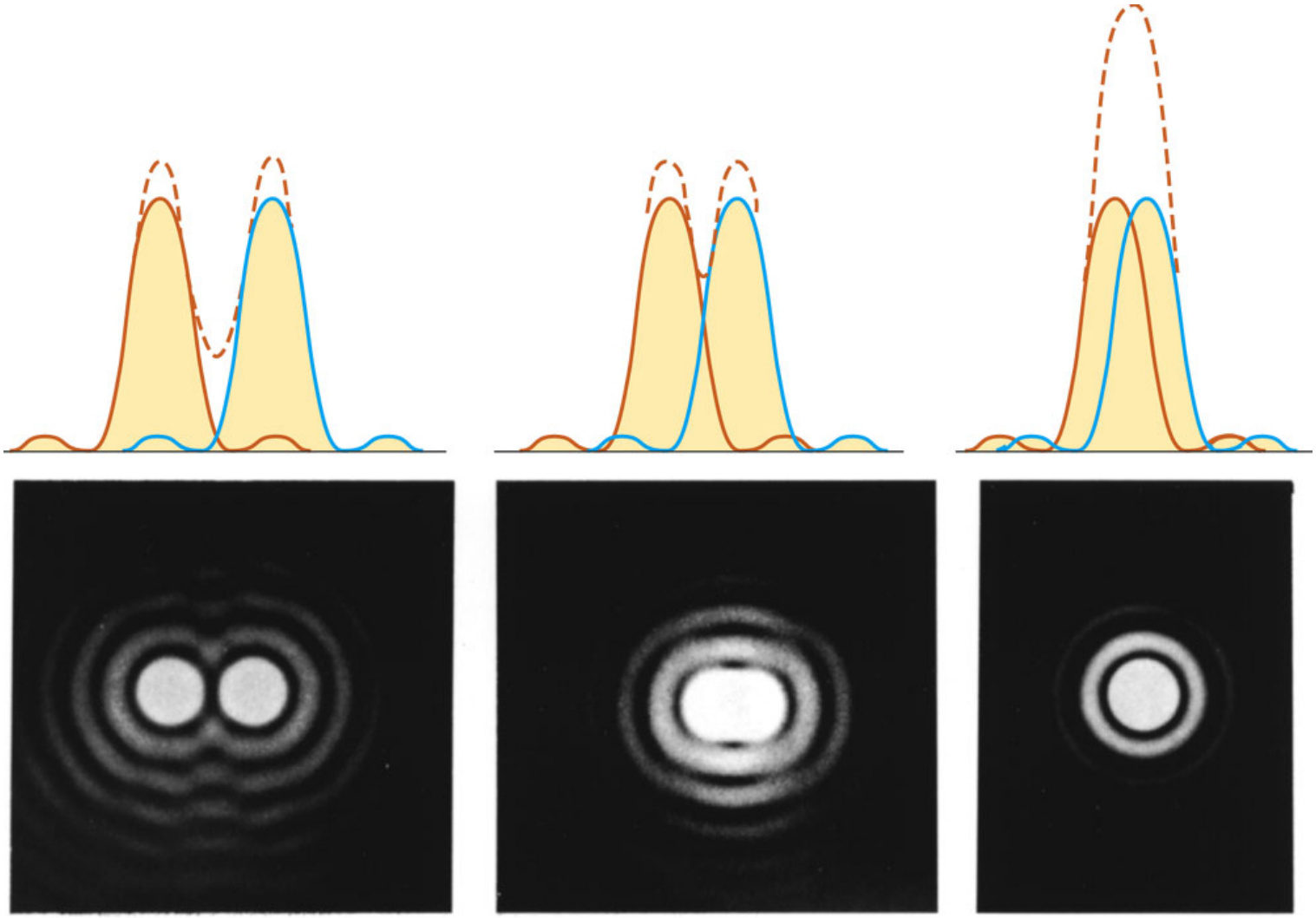
Demo is here

Defining the Limits of Sight-2 67



See more here.

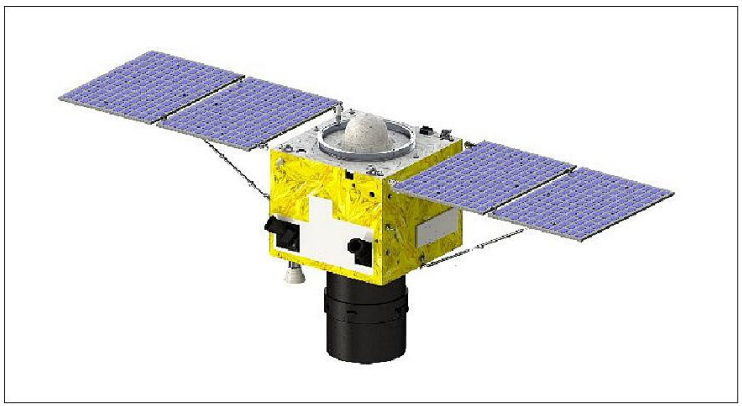
Defining the Limits of Sight-2 68



See more here.

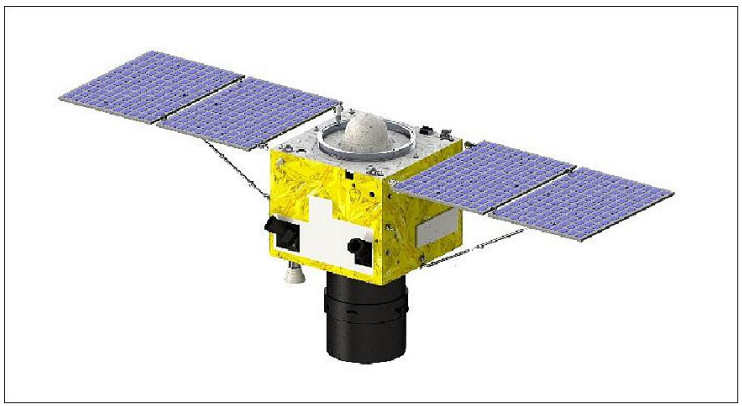
The Limits of Sight 69

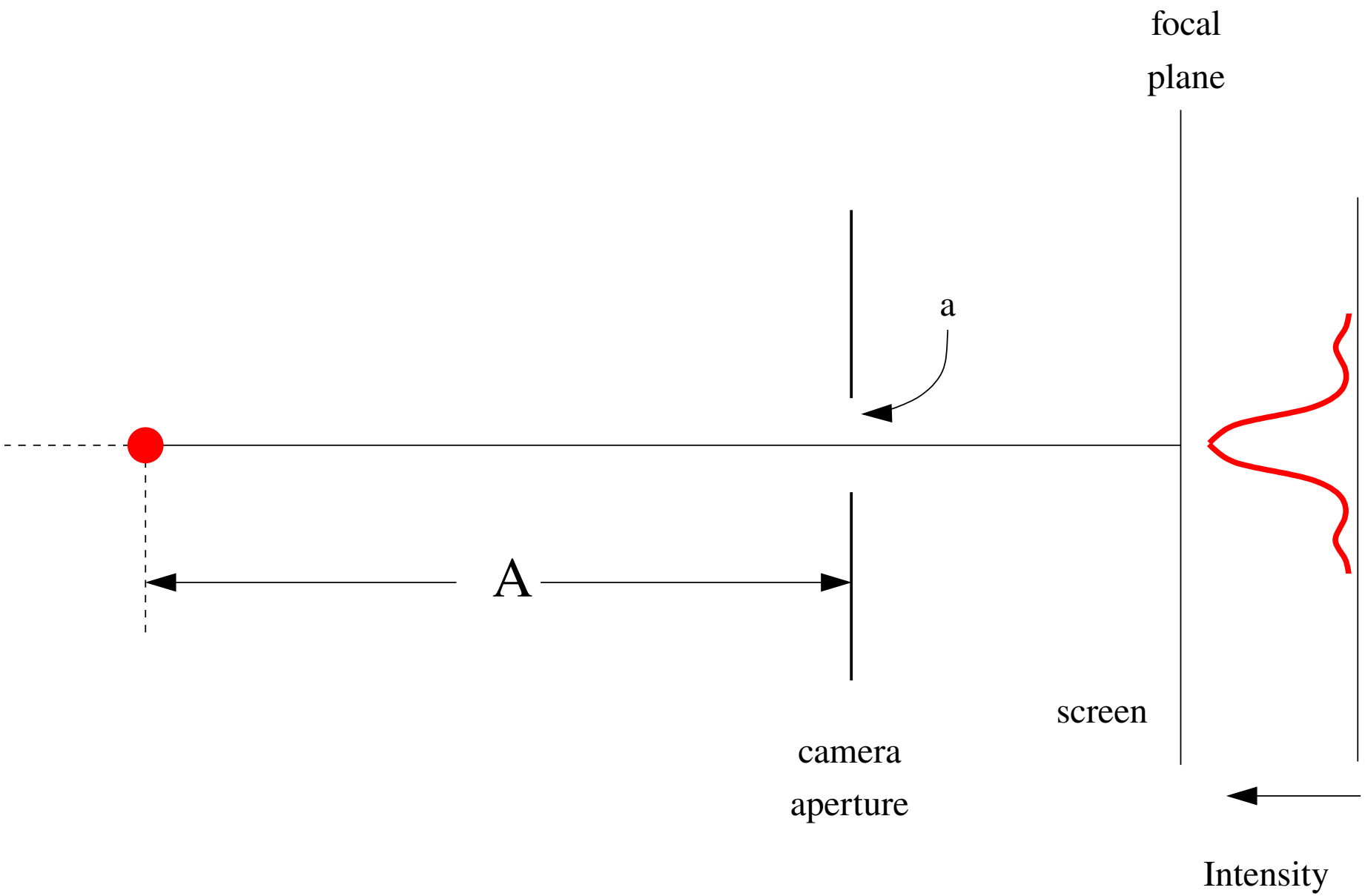
The SuperView 1B satellite is a commercial satellite designed to take surveillance photographs for sale and has been active since 2016. The cost for photos from the satellite archive is as low \$14. The aperture of the camera on the satellite is $a = 0.42\ m$ and the satellite operates $L = 530\ km$ above the Earth. What is the size of the smallest object visible to the camera? Visible light covers a range of wavelengths of $\lambda \approx 400 - 700\ nm$. What is the size of the smallest object visible to human eyes?

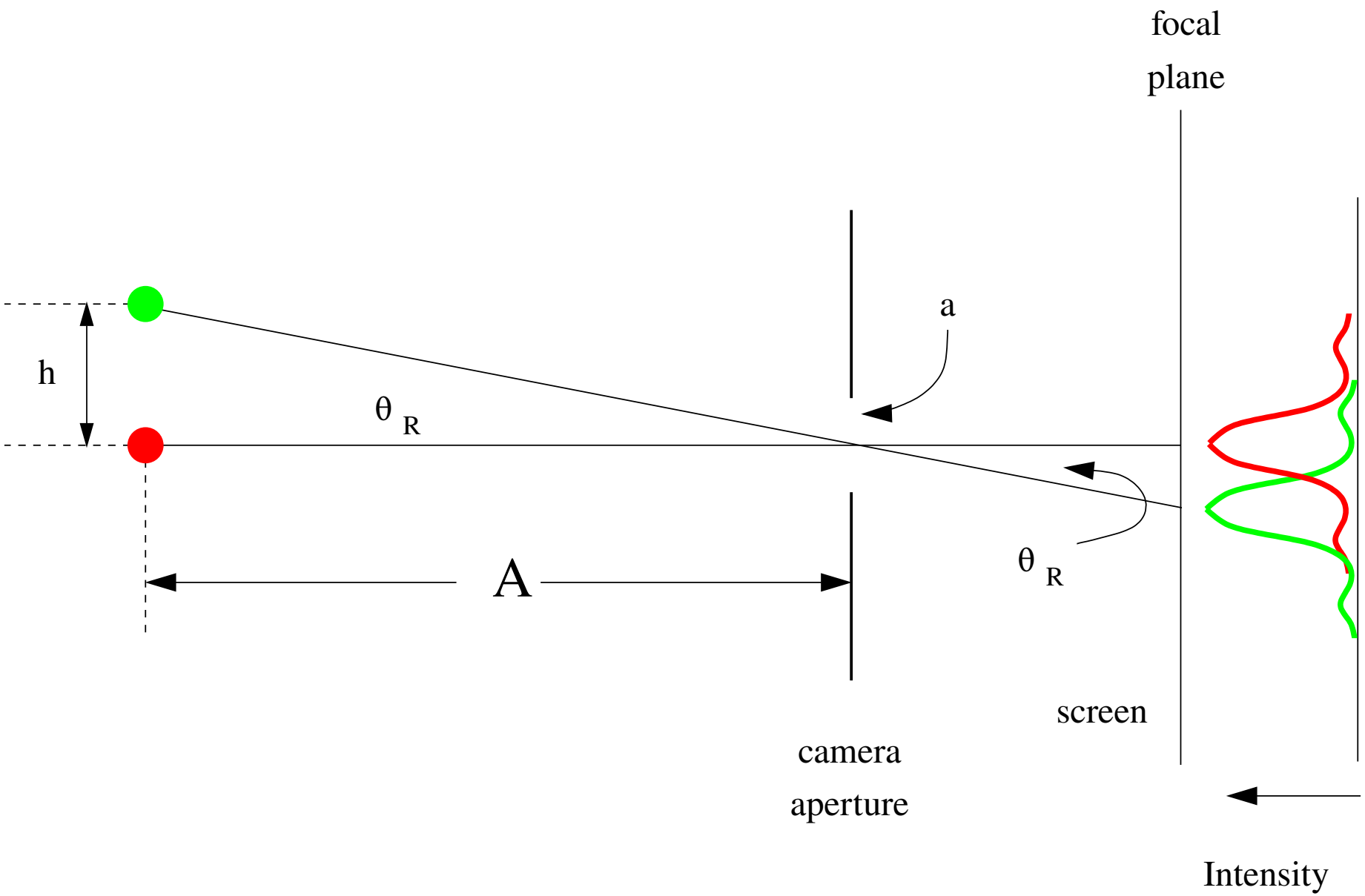


The Limits of Sight 70

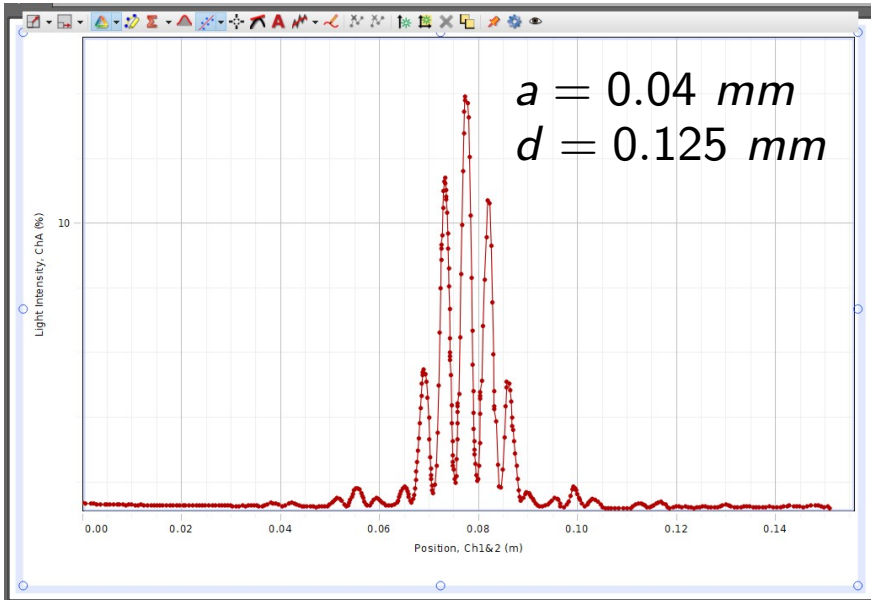
cial satellite designed to take
been active since 2016. The cost
low $14. The aperture of the
d the satellite operates
ıe size of the smallest object
s a range of wavelengths of
he smallest object visible to

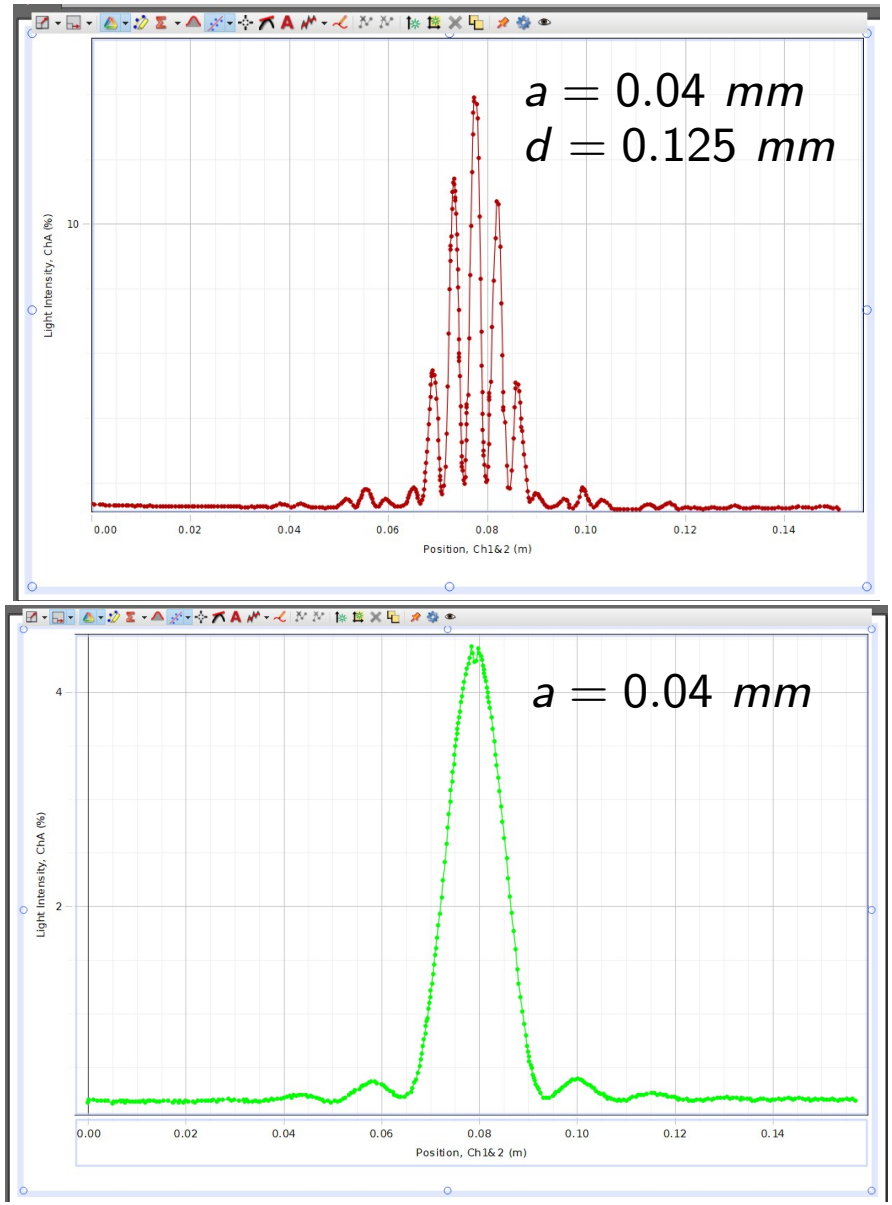


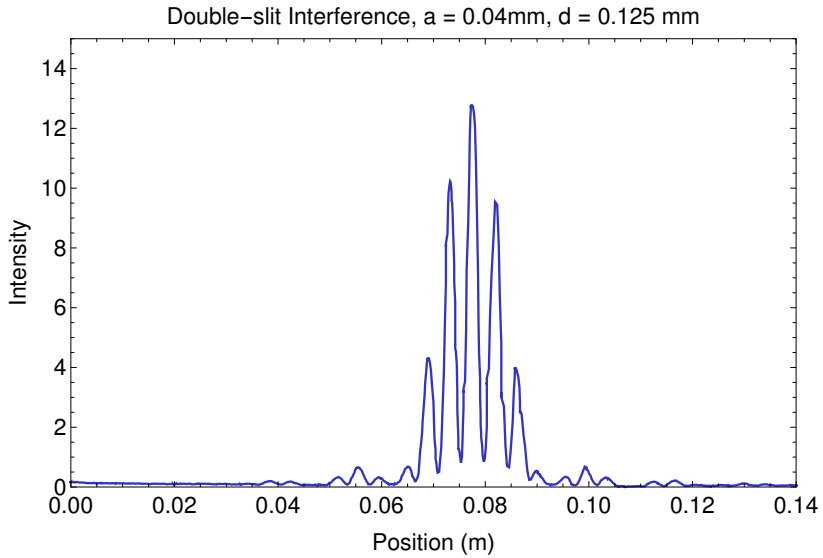

focal
plane
a
A
screen
camera
aperture
Intensity

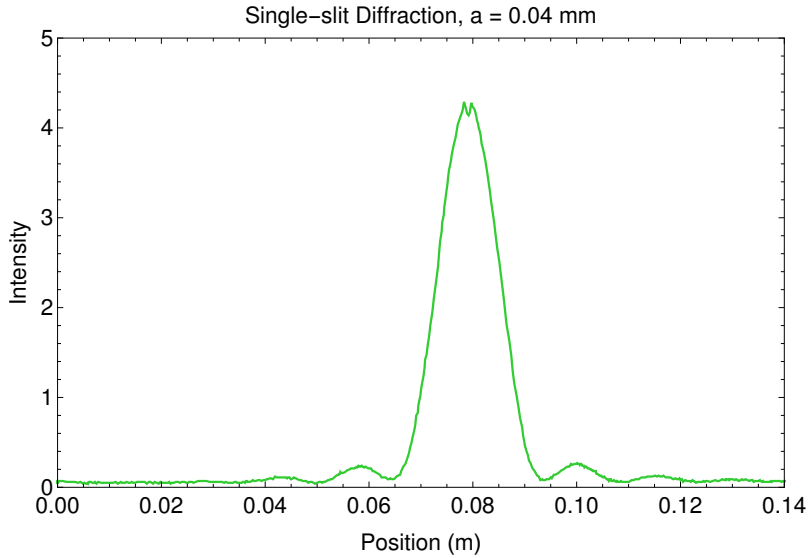

focal
plane
a
h
θ R
θ R
A
screen
camera
aperture
Intensity

The Diffraction Lab 73

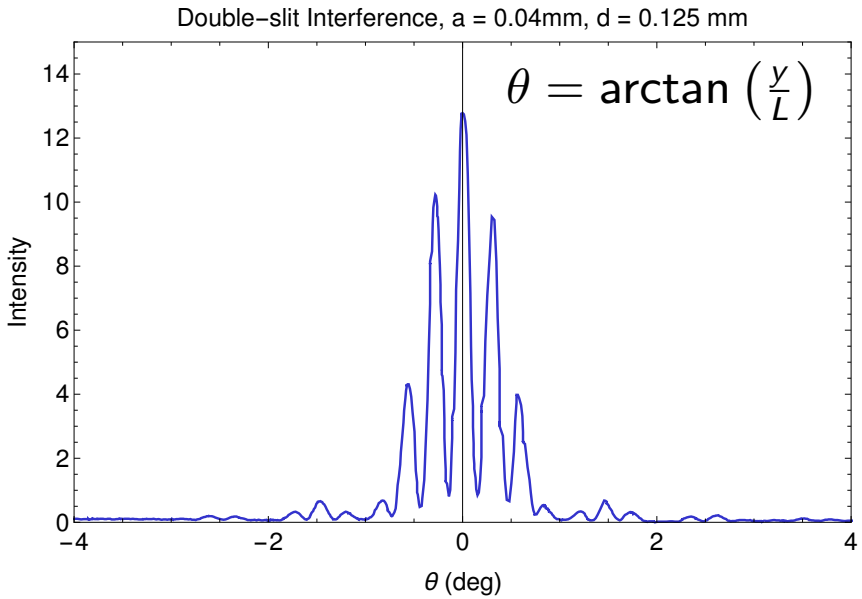


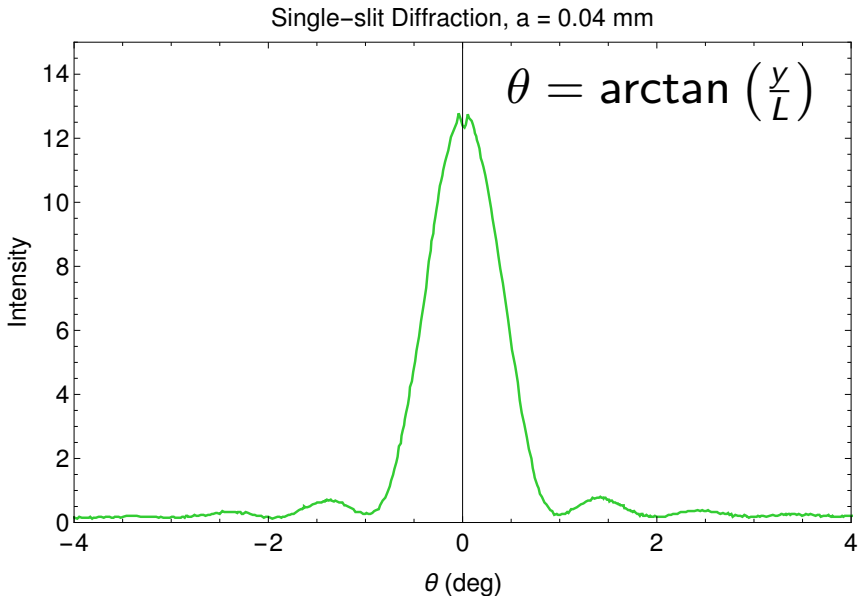

$a = 0.04\ mm$
$d = 0.125\ mm$
Light Intensity, ChA (%)
10
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Position, Ch1&2 (m)
$a = 0.04\ mm$
Light Intensity, ChA (%)
4
2
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Position, Ch1&2 (m)

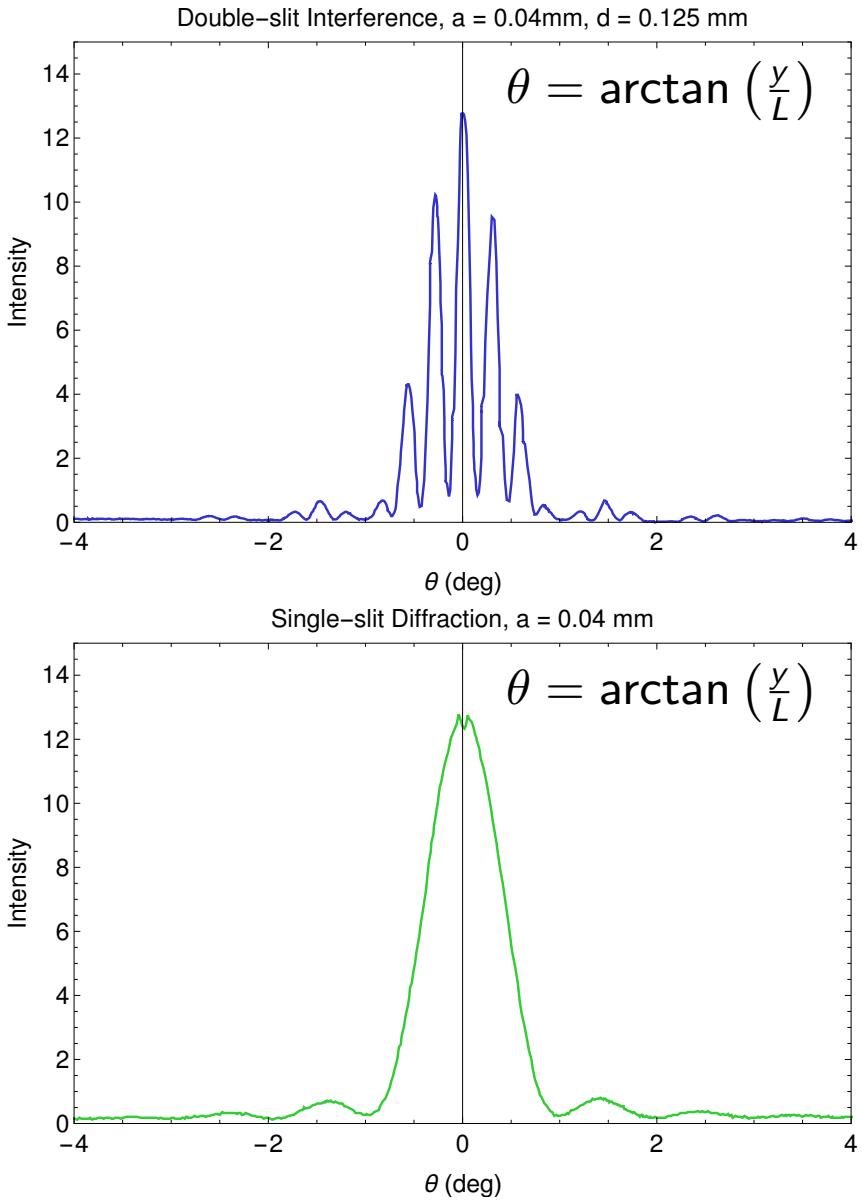

Double−slit Interference, a = 0.04mm, d = 0.125 mm
Intensity
Position (m)
0
2
4
6
8
10
12
14
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14

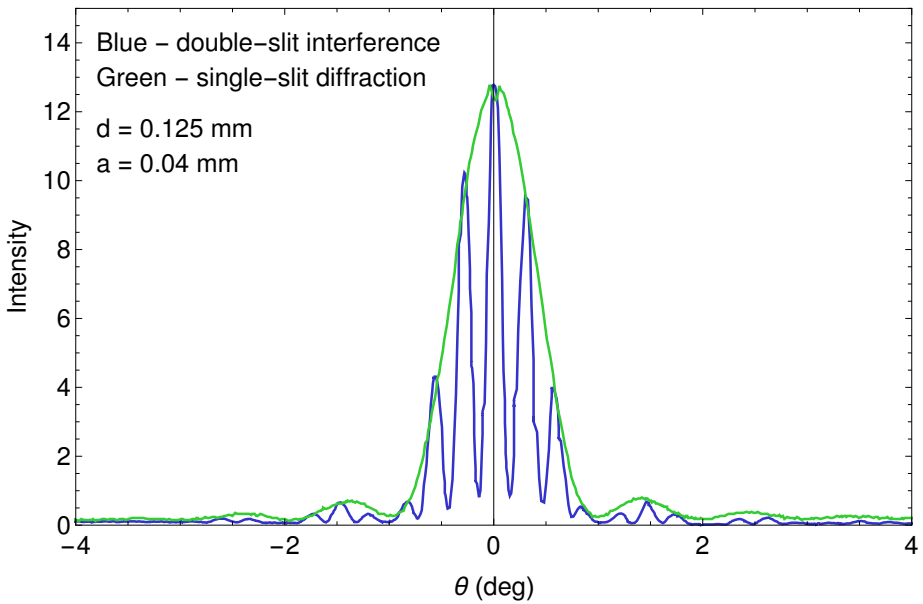

Single−slit Diffraction, a = 0.04 mm
Intensity
Position (m)
0
1
2
3
4
5
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14

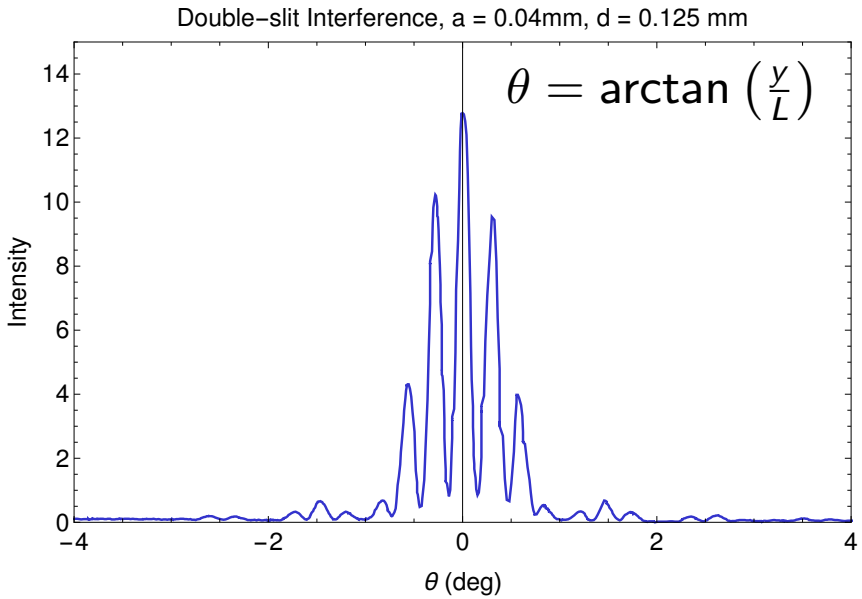
The Diffraction Lab 76

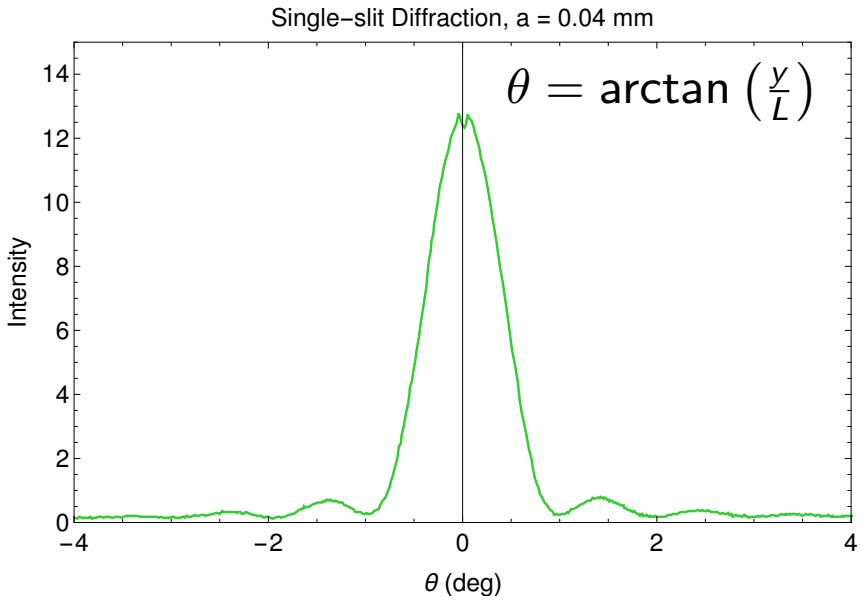


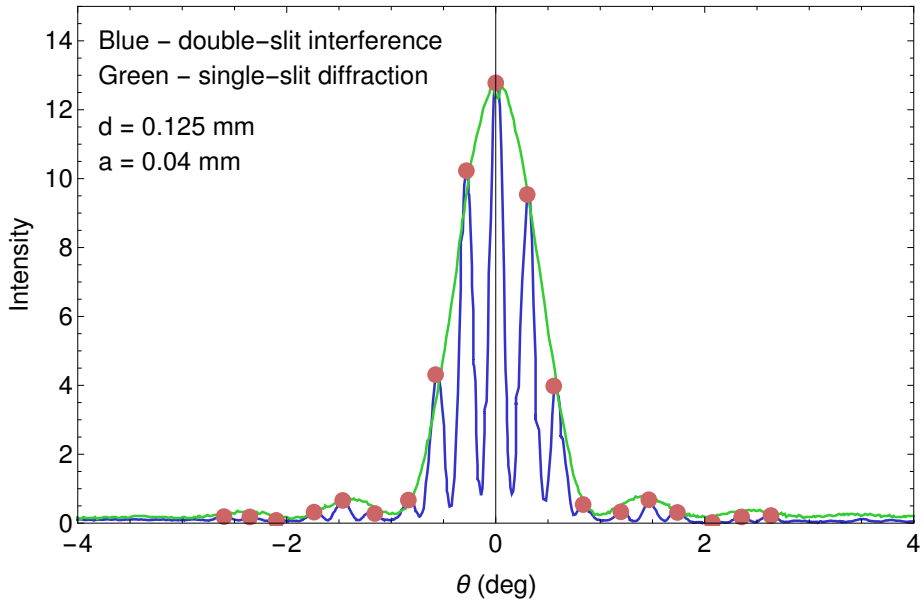


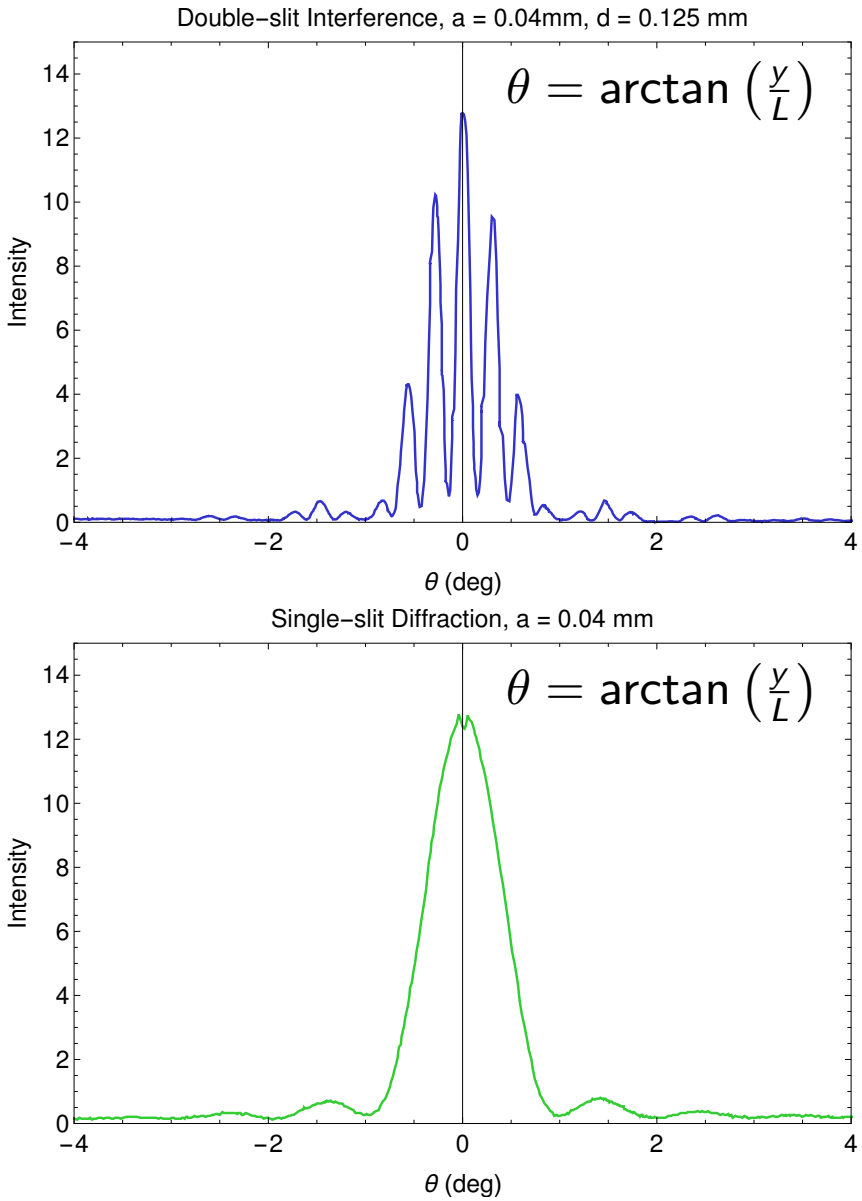

Double−slit Interference, a = 0.04mm, d = 0.125 mm
θ = arctan (y/L)
Intensity
θ (deg)
Single−slit Diffraction, a = 0.04 mm
θ = arctan (y/L)
Intensity
θ (deg)

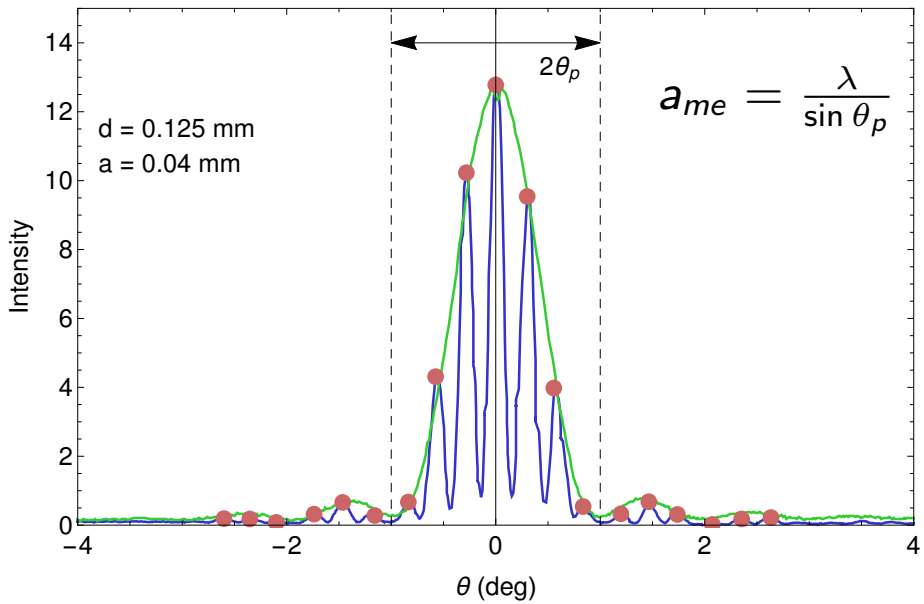

Blue − double−slit interference
Green − single−slit diffraction
d = 0.125 mm
a = 0.04 mm
Intensity
θ (deg)


Double−slit Interference, a = 0.04mm, d = 0.125 mm
$\theta = \arctan\left(\frac{y}{L}\right)$
Intensity
θ (deg)

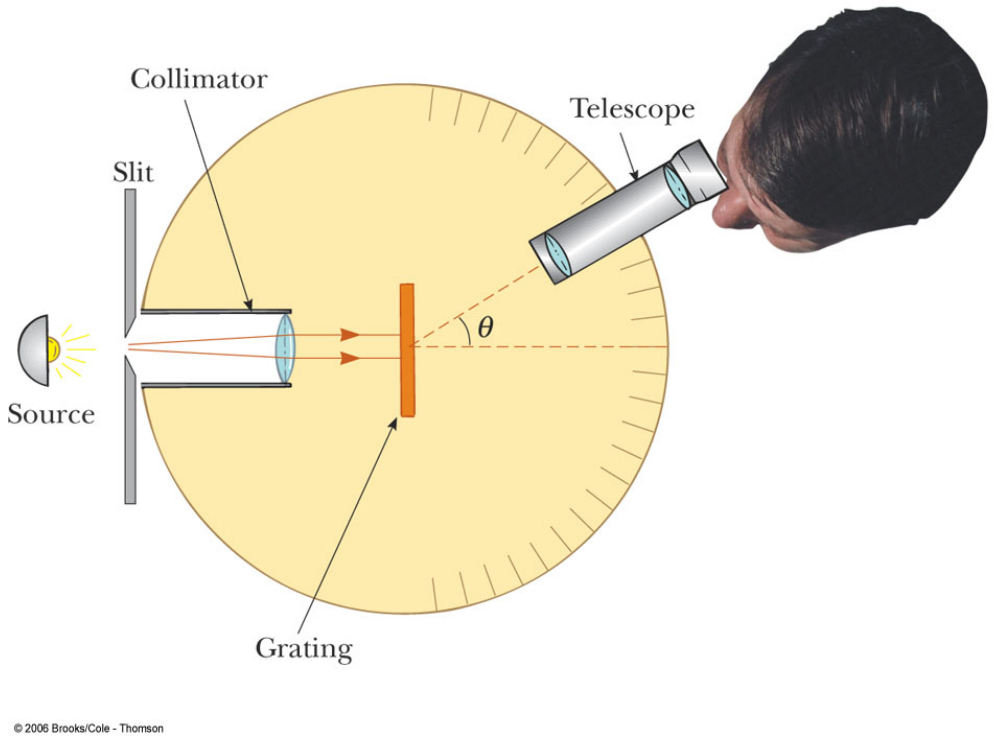

Single−slit Diffraction, a = 0.04 mm
$\theta = \arctan\left(\frac{y}{L}\right)$
Intensity
θ (deg)

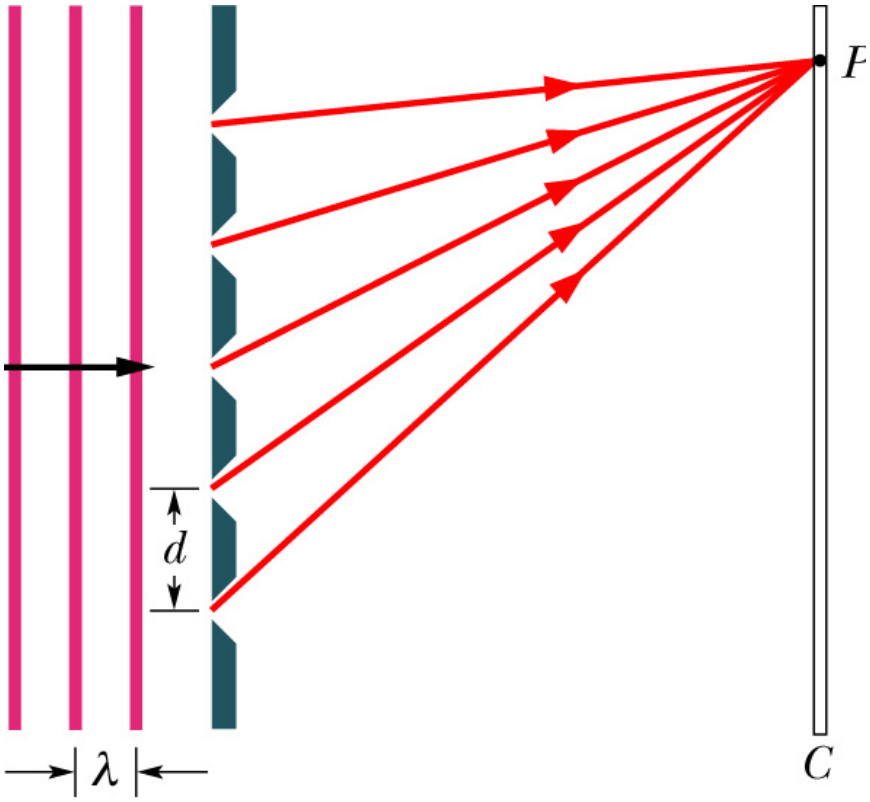

Blue − double−slit interference
Green − single−slit diffraction
d = 0.125 mm
a = 0.04 mm
Intensity
θ (deg)

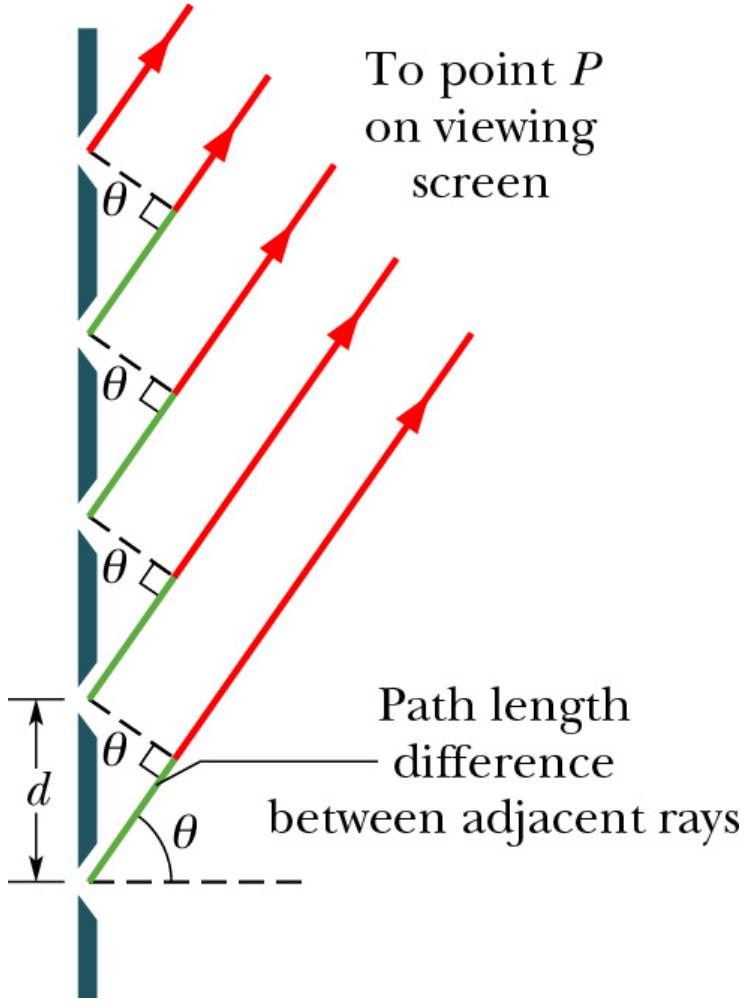

Double−slit Interference, a = 0.04mm, d = 0.125 mm
θ = arctan (y/L)
Intensity
θ (deg)
Single−slit Diffraction, a = 0.04 mm
θ = arctan (y/L)
Intensity
θ (deg)


d = 0.125 mm
a = 0.04 mm
2θp
a_me = λ / sin θp
Intensity
θ (deg)

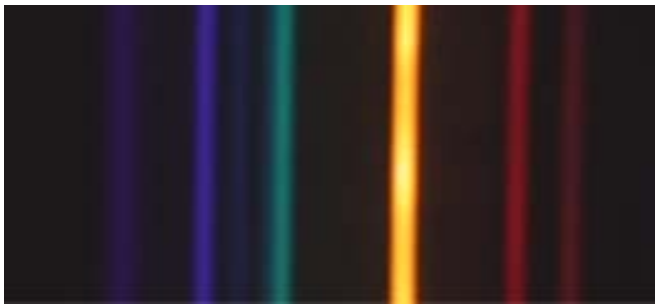
Light of wavelength $\lambda = 600\ nm$ is incident normally on a diffraction grating in a spectrometer. Two adjacent maxima occur at angles given by $\sin\theta_1 = 0.2$ and $\sin\theta_2 = 0.3$. The fourth-order maxima are missing. What is the separation between adjacent slits?




P
d
λ
C


To point P
on viewing
screen
θ
θ
θ
θ
d
θ
Path length
difference
between adjacent rays

What You See. 82



Visible emission spectrum of helium.

Induction Results 83