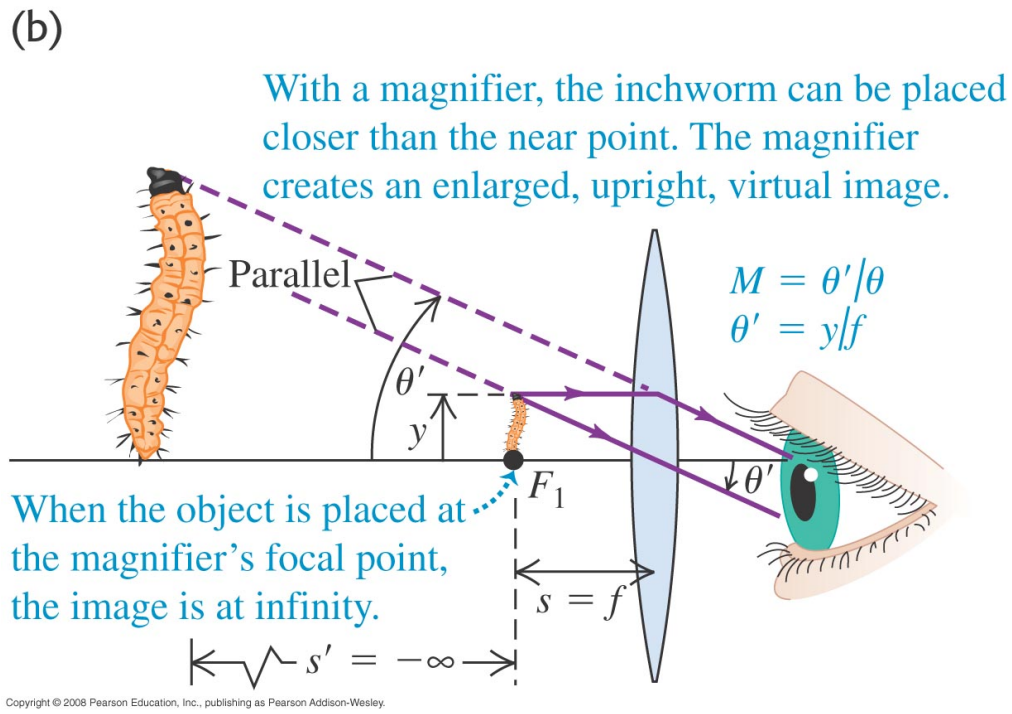
Figure 34.51b



Clicker question

When using a magnifier, if a smaller focal length lens is used it will (compared to using the original magnifier):

a) Make the image larger on the retina.

b) Make the image the same on the retina.

c) Make the image smaller on the retina.

Clicker question

When using a magnifier, if a smaller focal length lens is used it will (compared to using the original magnifier):

a) Make the image larger on the retina.

b) Make the image the same on the retina.

c) Make the image smaller on the retina.

Figure 34.52b

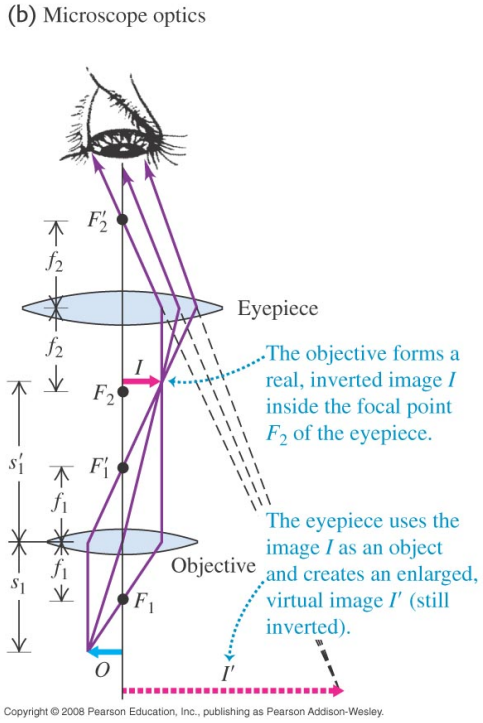


Figure 34.53

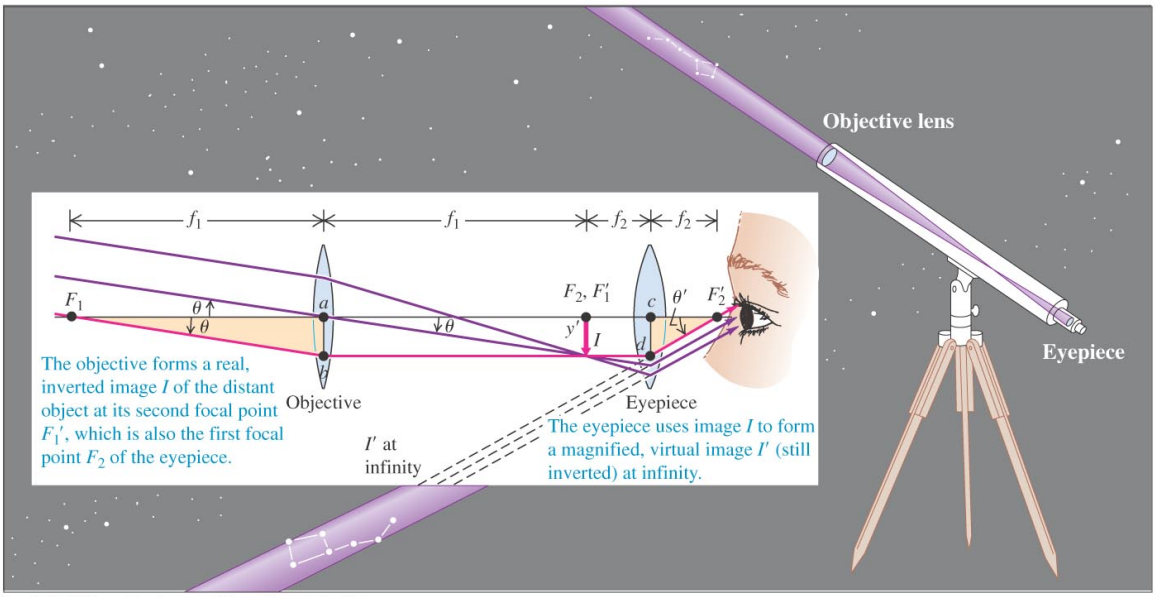
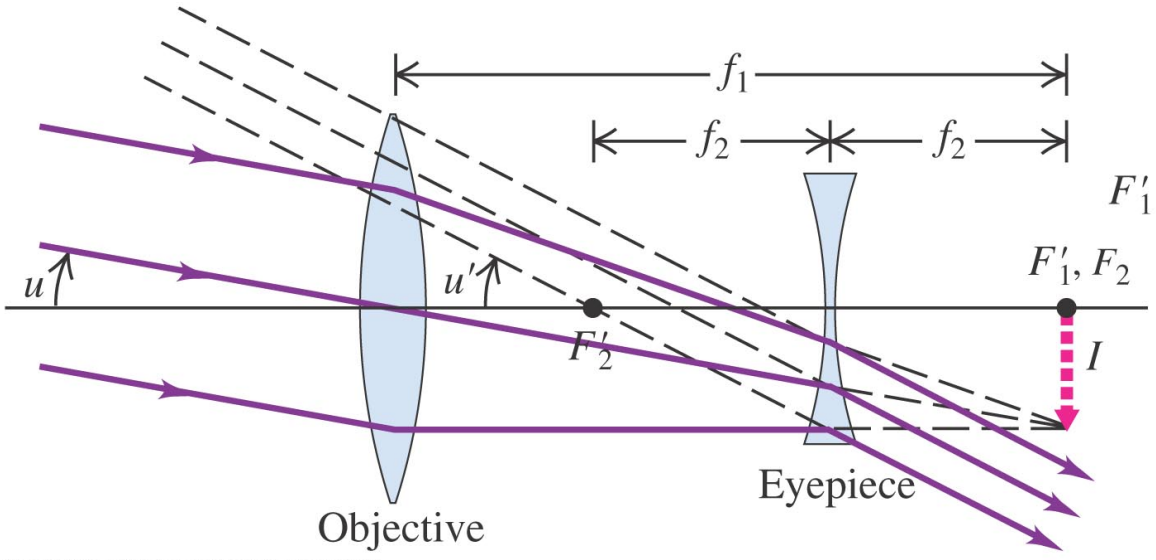


Figure 34.64



Clicker question

You are choosing lenses for a telescope that you will use to look at the Moon and planets. You should select

A. an objective lens with a long focal length and an eyepiece lens with an even longer focal length.

B. an objective lens with a long focal length and an eyepiece lens with a shorter focal length.

C. an objective lens with a short focal length and an eyepiece lens with a longer focal length.

D. an objective lens with a short focal length and an eyepiece lens with an even shorter focal length.

Clicker question

You are choosing lenses for a telescope that you will use to look at the Moon and planets. You should select

A. an objective lens with a long focal length and an eyepiece lens with an even longer focal length.

B. an objective lens with a long focal length and an eyepiece lens with a shorter focal length.

C. an objective lens with a short focal length and an eyepiece lens with a longer focal length.

D. an objective lens with a short focal length and an eyepiece lens with an even shorter focal length.

Figure 35.2a

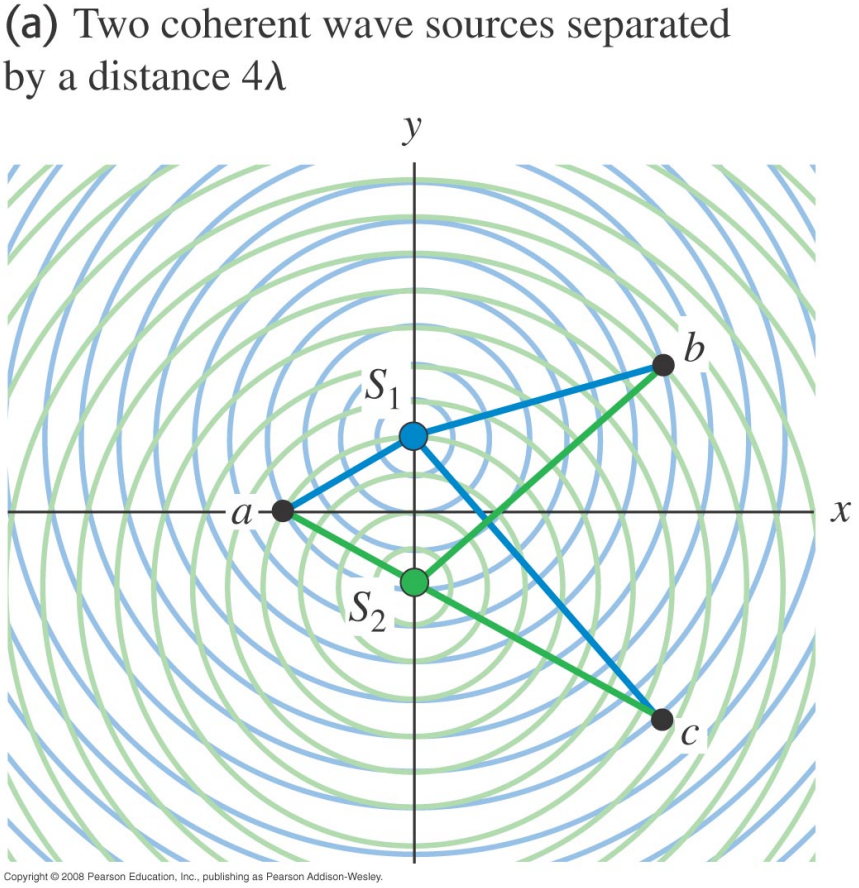


Figure 35.5a

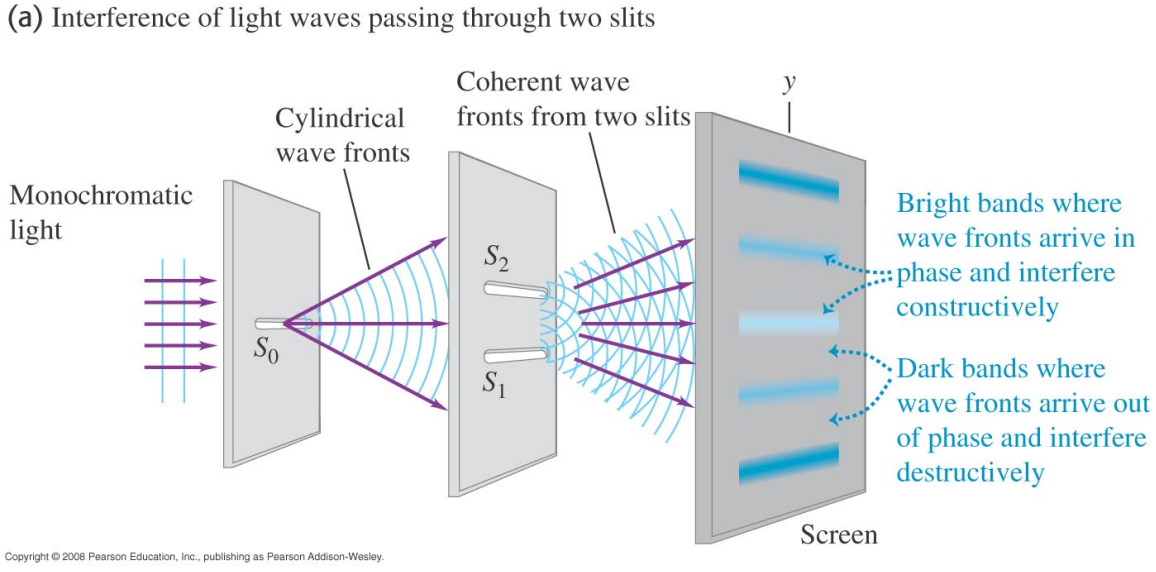


Figure 35.2a

(a) Two coherent wave sources separated by a distance 4λ

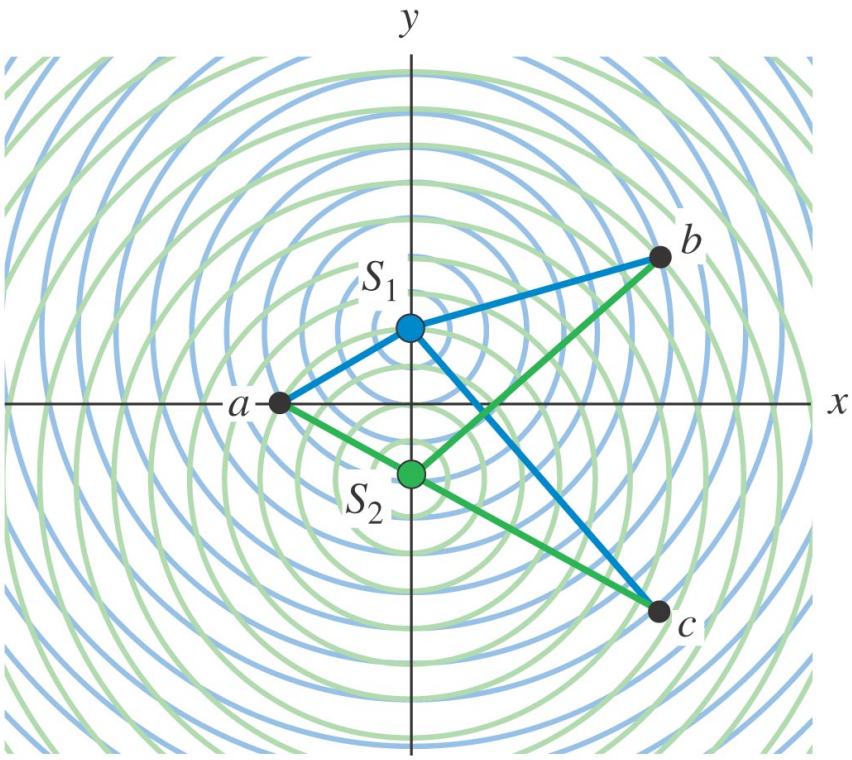


Figure 35.2b

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

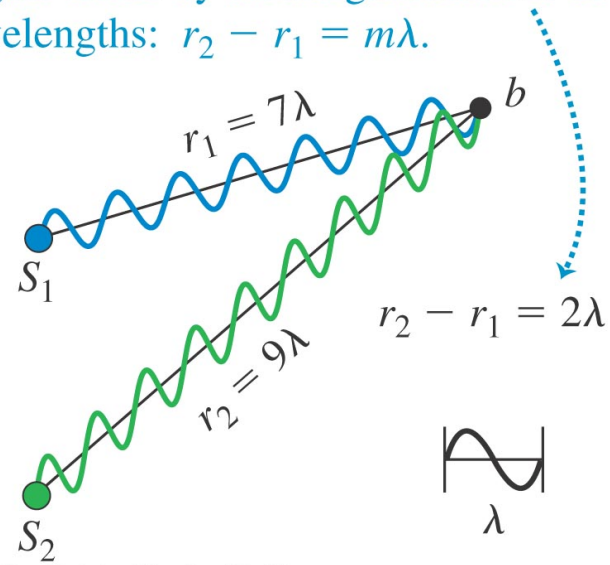
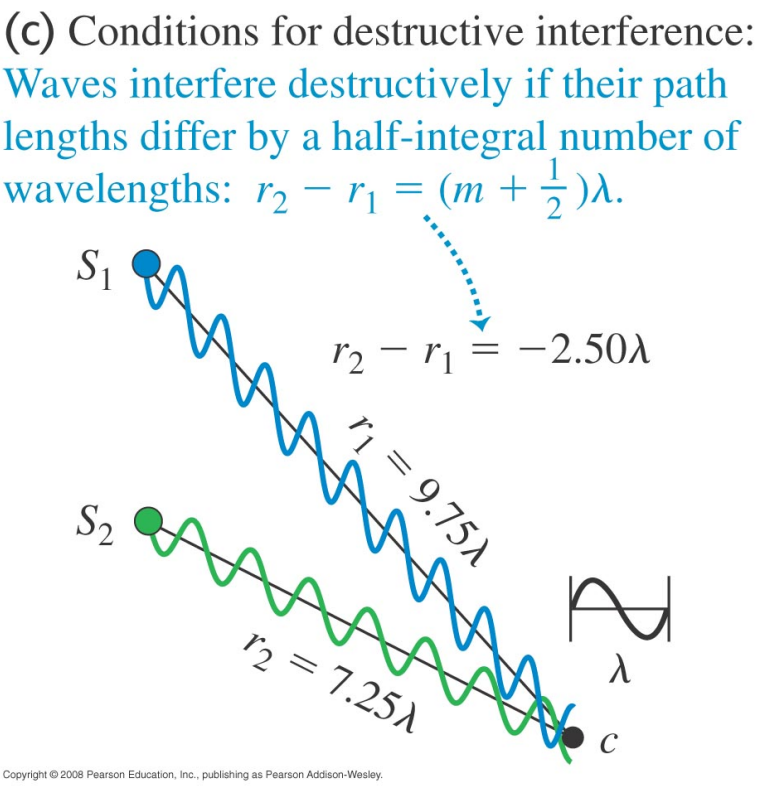


Figure 35.2c



Clicker question

Two sources S_1 and S_2 oscillating in phase emit sinusoidal waves.

Point *P* is 7.3 wavelengths from source S_1 and 4.3 wavelengths from source S_2. As a result, at point *P* there is

A. constructive interference.

B. destructive interference.

C. neither constructive nor destructive interference.

D. not enough information given to decide.

Clicker question

Two sources S_1 and S_2 oscillating in phase emit sinusoidal waves.

Point *P* is 7.3 wavelengths from source S_1 and 4.3 wavelengths from source S_2. As a result, at point *P* there is

A. constructive interference.

B. destructive interference.

C. neither constructive nor destructive interference.

D. not enough information given to decide.

Clicker question

Two sources S_1 and S_2 oscillating in phase emit sinusoidal waves.

Point P is 7.3 wavelengths from source S_1 and 4.6 wavelengths from source S_2. As a result, at point P there is

A. constructive interference.

B. destructive interference.

C. neither constructive nor destructive interference.

D. not enough information given to decide.

Clicker question

Two sources S_1 and S_2 oscillating in phase emit sinusoidal waves.

Point P is 7.3 wavelengths from source S_1 and 4.6 wavelengths from source S_2. As a result, at point P there is

A. constructive interference.

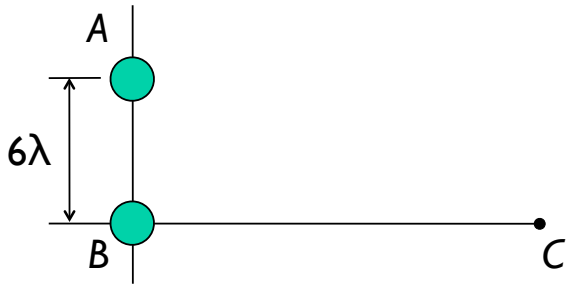
B. destructive interference.

C. neither constructive nor destructive interference.

D. not enough information given to decide.

Clicker Question

Two radio antennas radiating in phase are located at points *A* and *B*, which are 6 wavelengths apart. A radio receiver is moved along a line from point *B* to point *C*.



At what distances from point *B* will the receiver detect an intensity *maximum?*

A. 4.5λ

B. 8λ

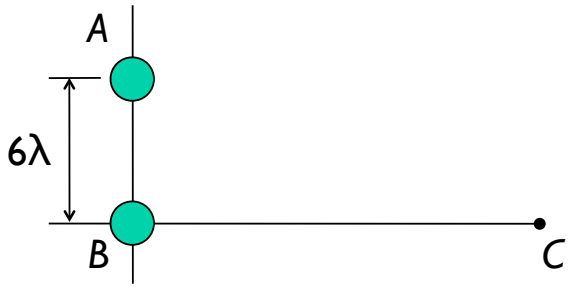
C. 9λ

D. both A. and B.

E. all of A., B. and C.

Clicker Question

Two radio antennas radiating in phase are located at points *A* and *B*, which are 6 wavelengths apart. A radio receiver is moved along a line from point *B* to point *C*.



At what distances from point *B* will the receiver detect an intensity *maximum?*

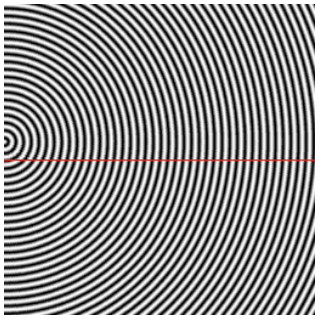
A. 4.5λ

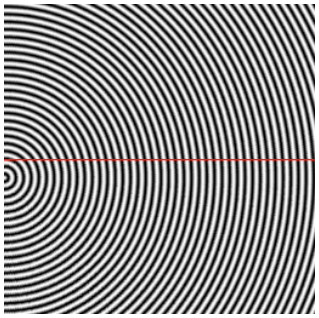
B. 8λ

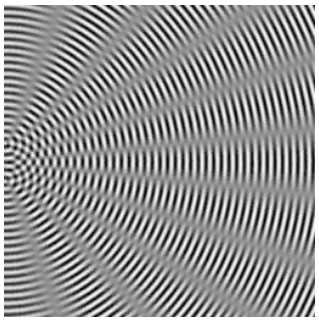
C. 9λ

D. both A. and B.

E. all of A., B. and C.







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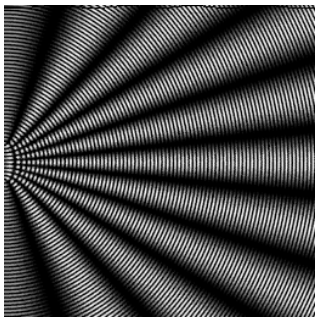
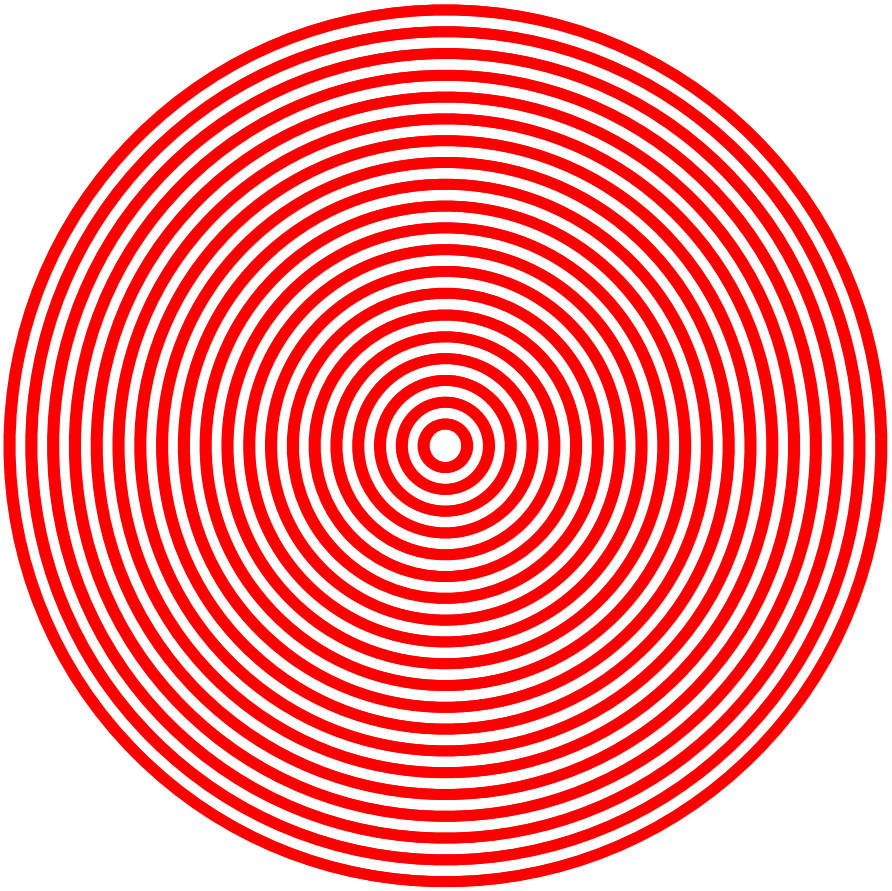
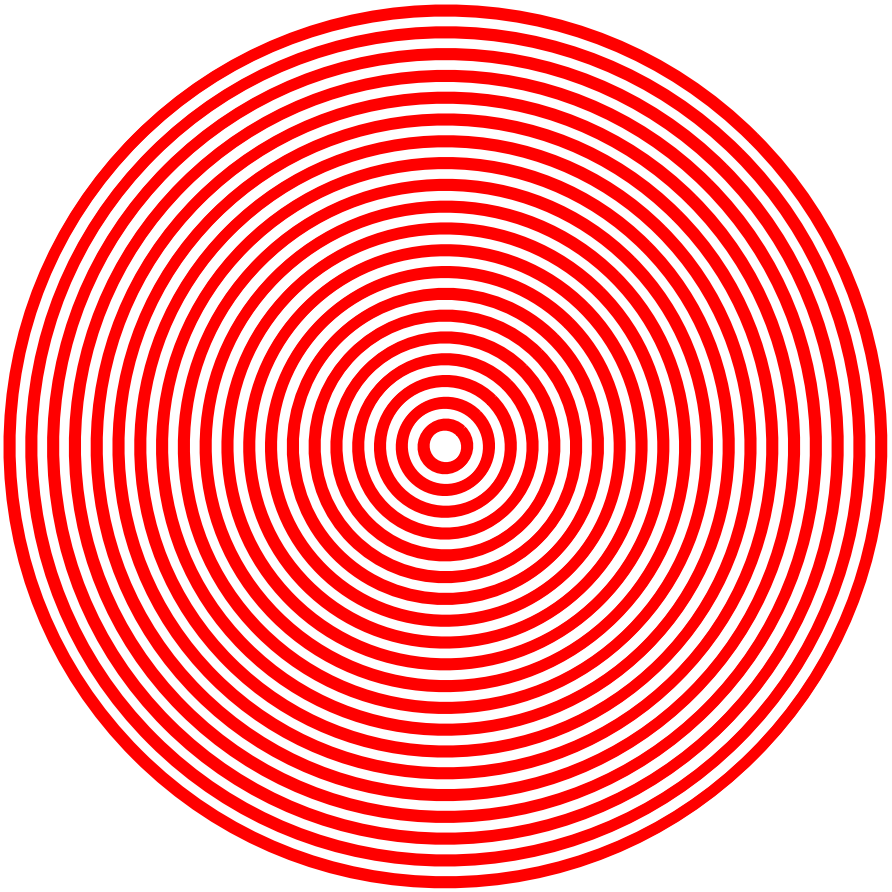
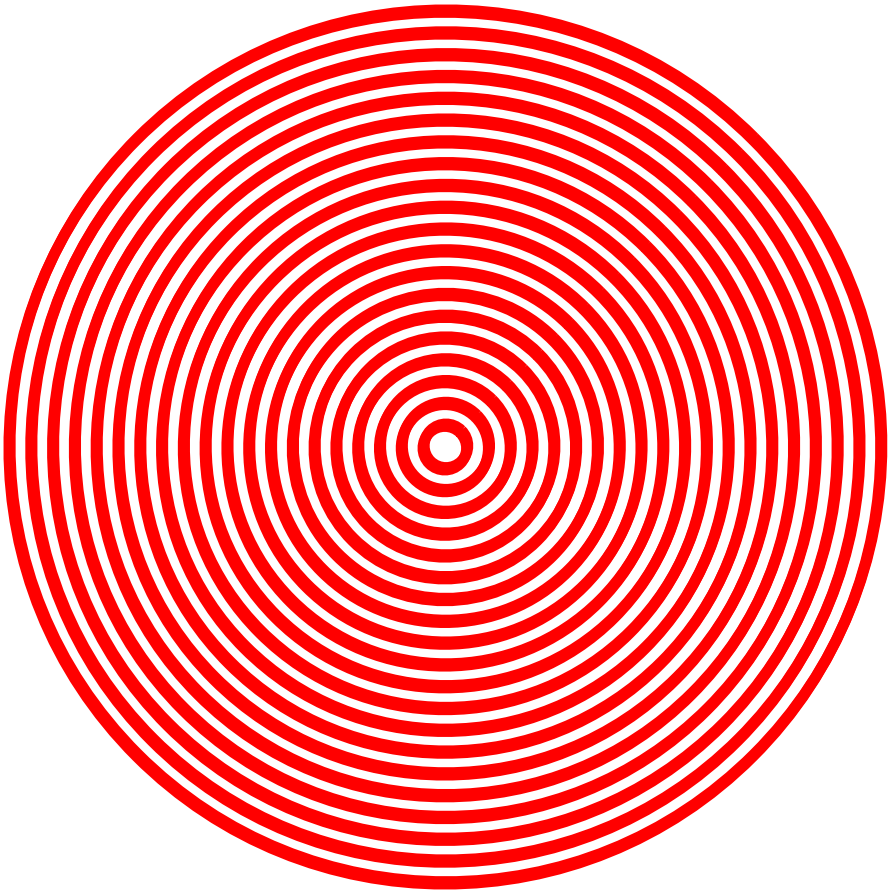
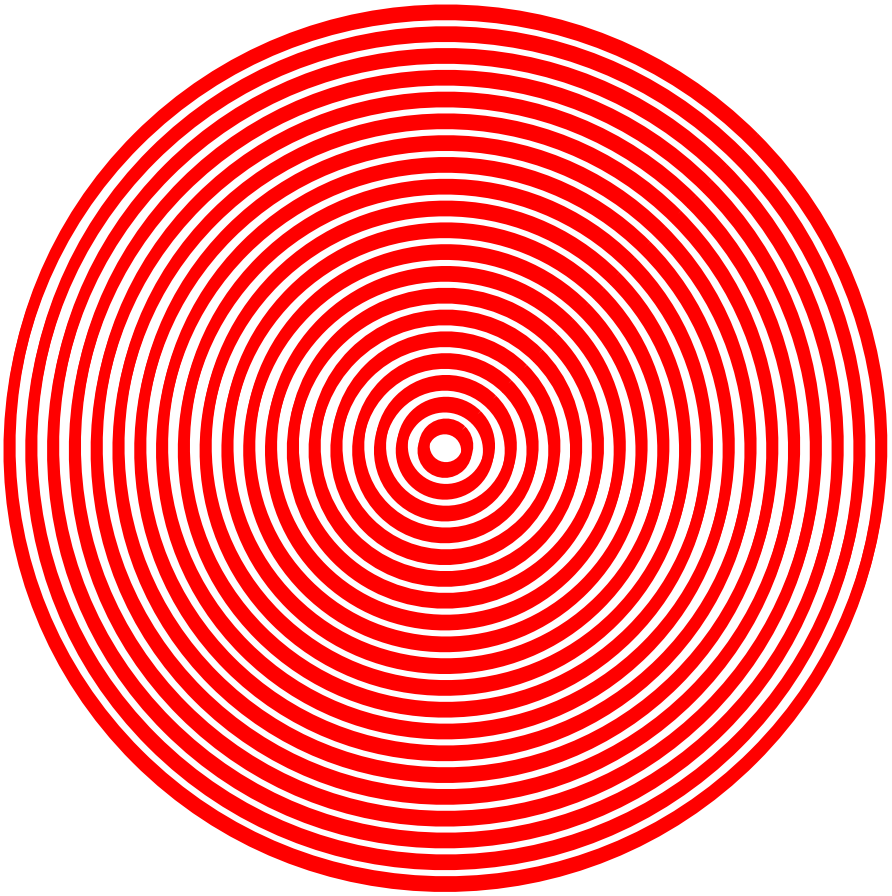


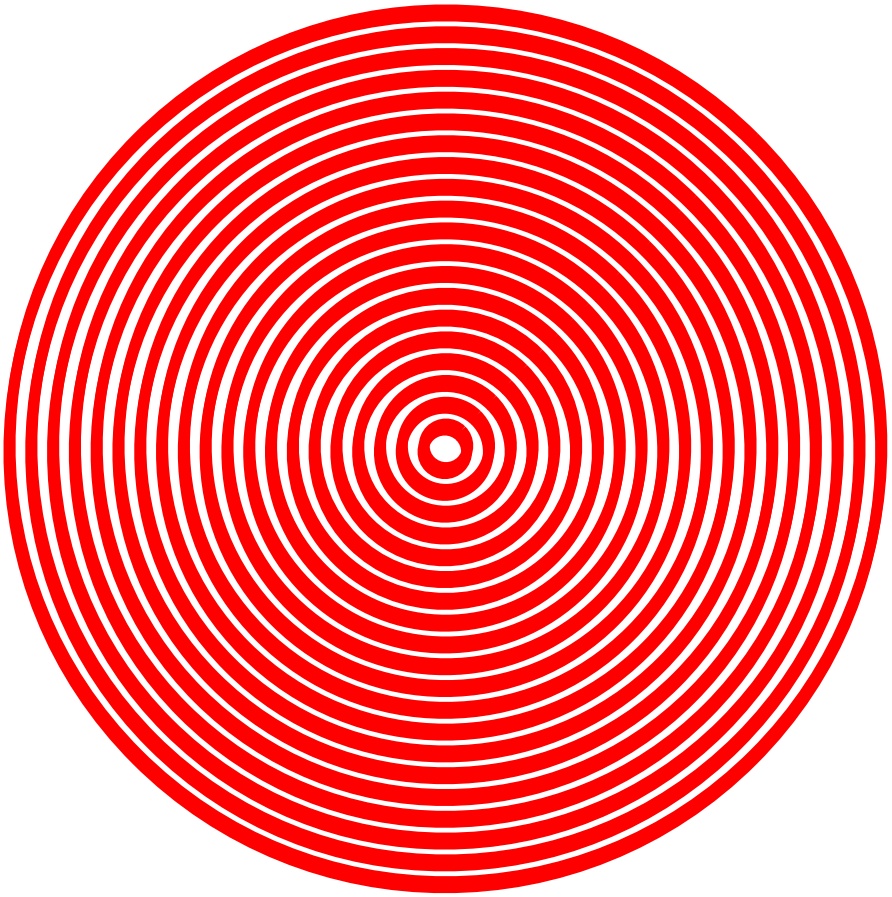
Intensity

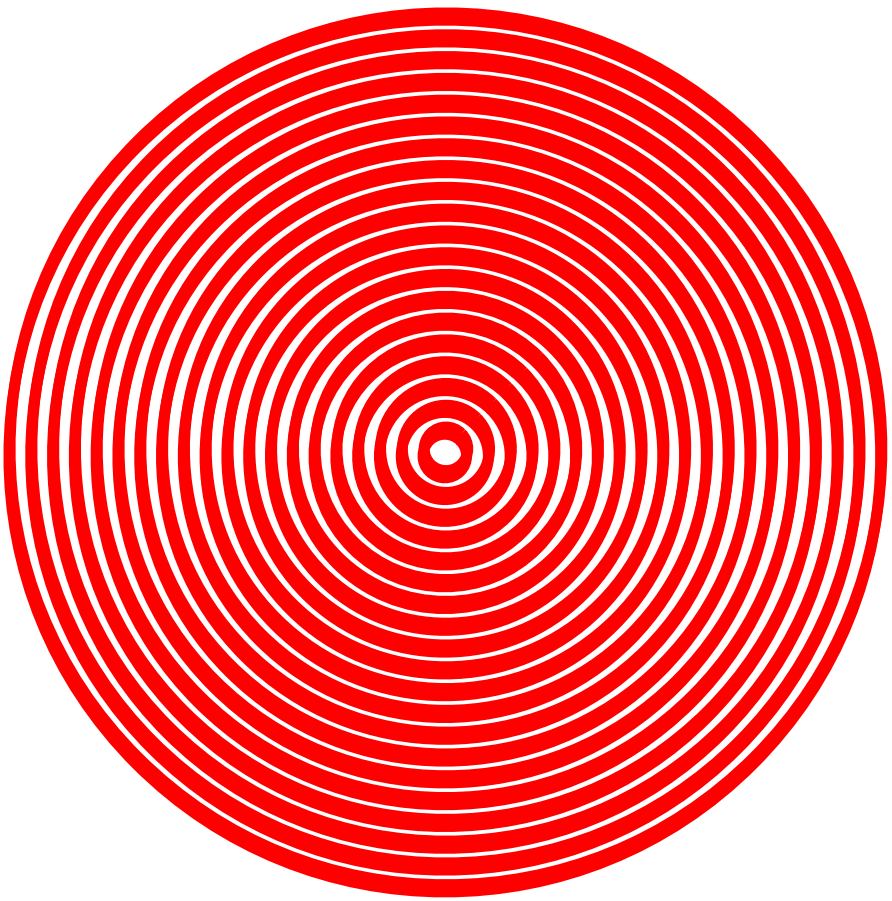


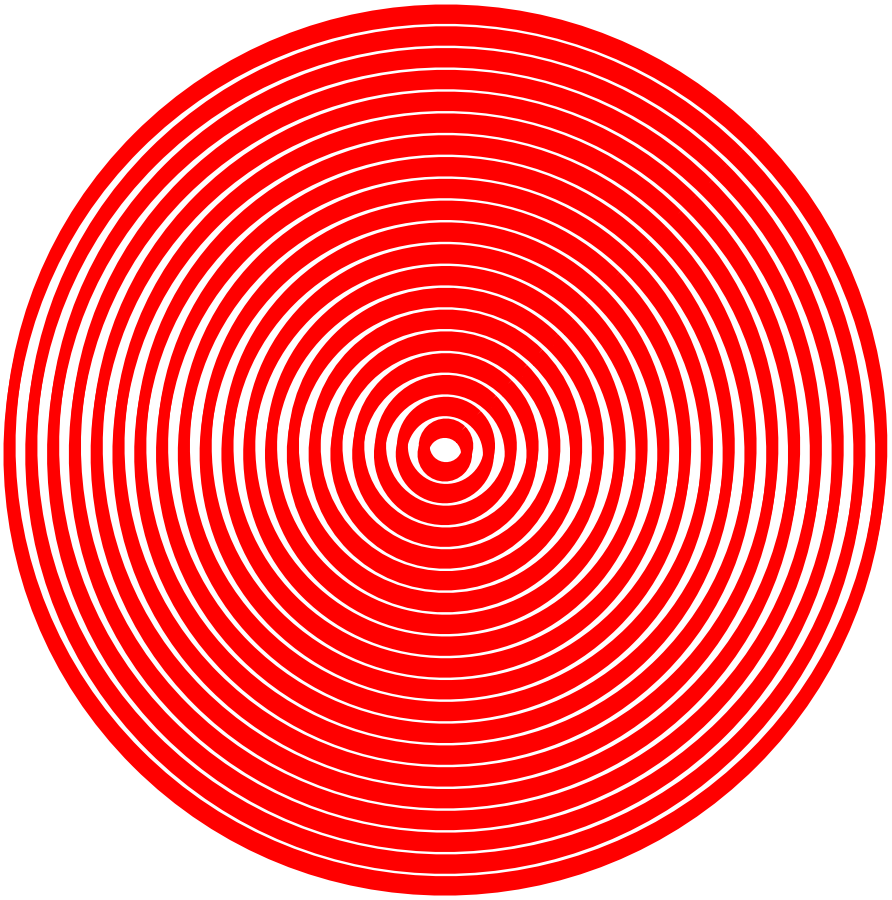


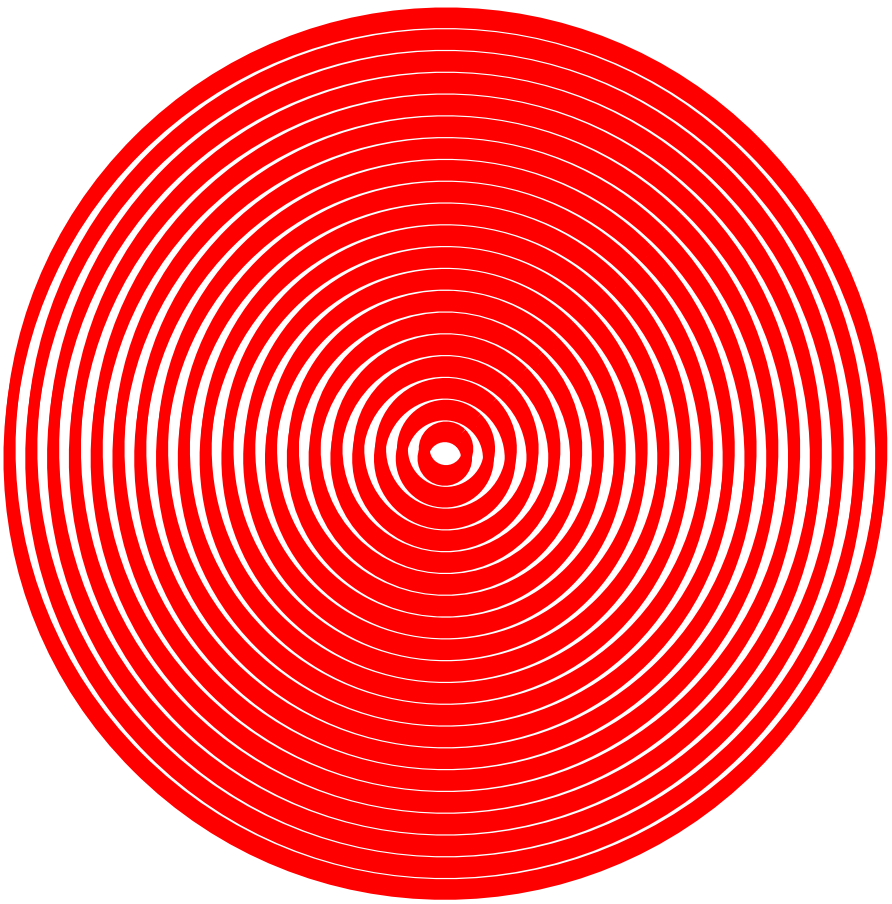


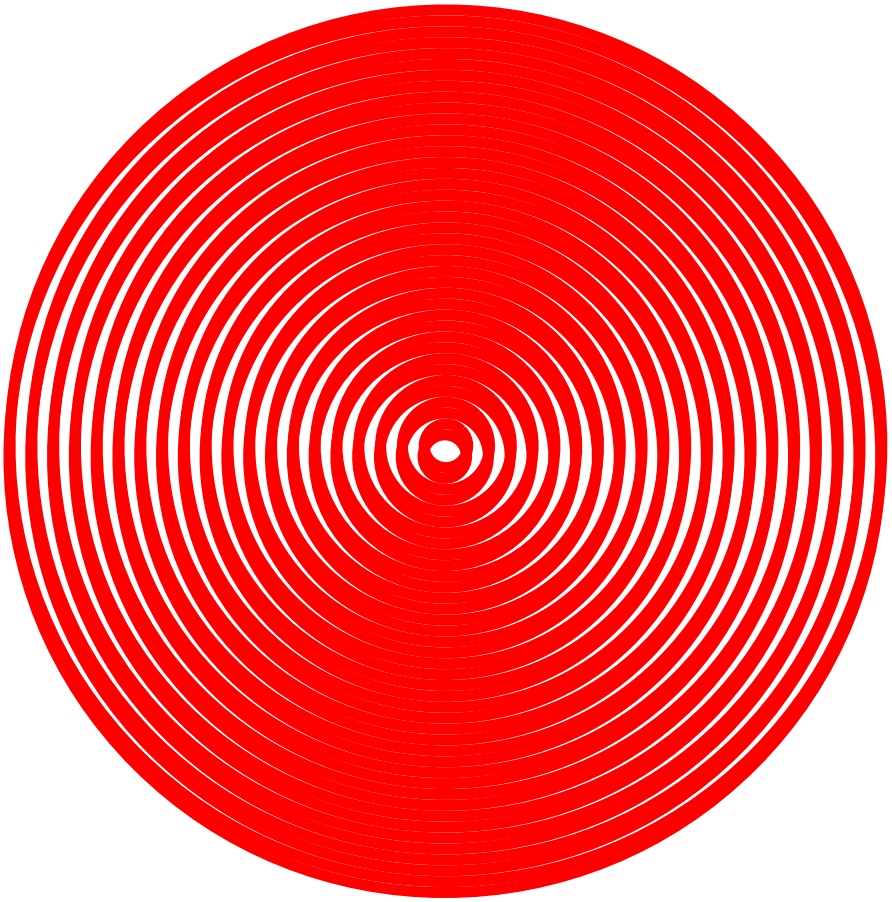


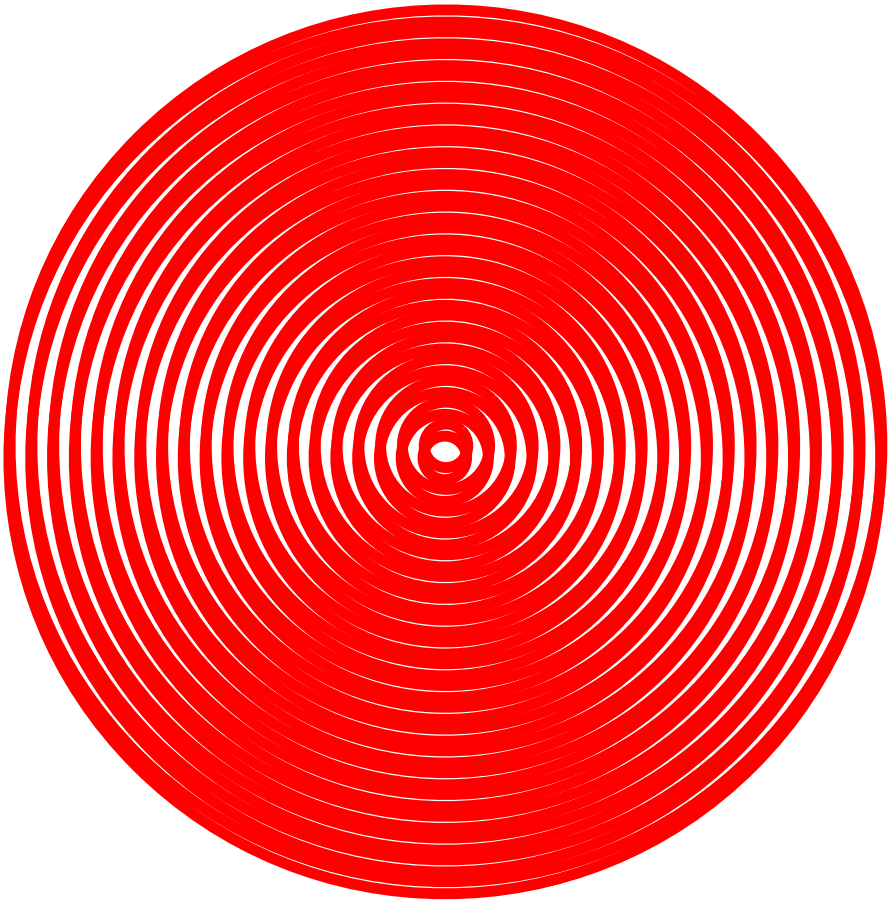


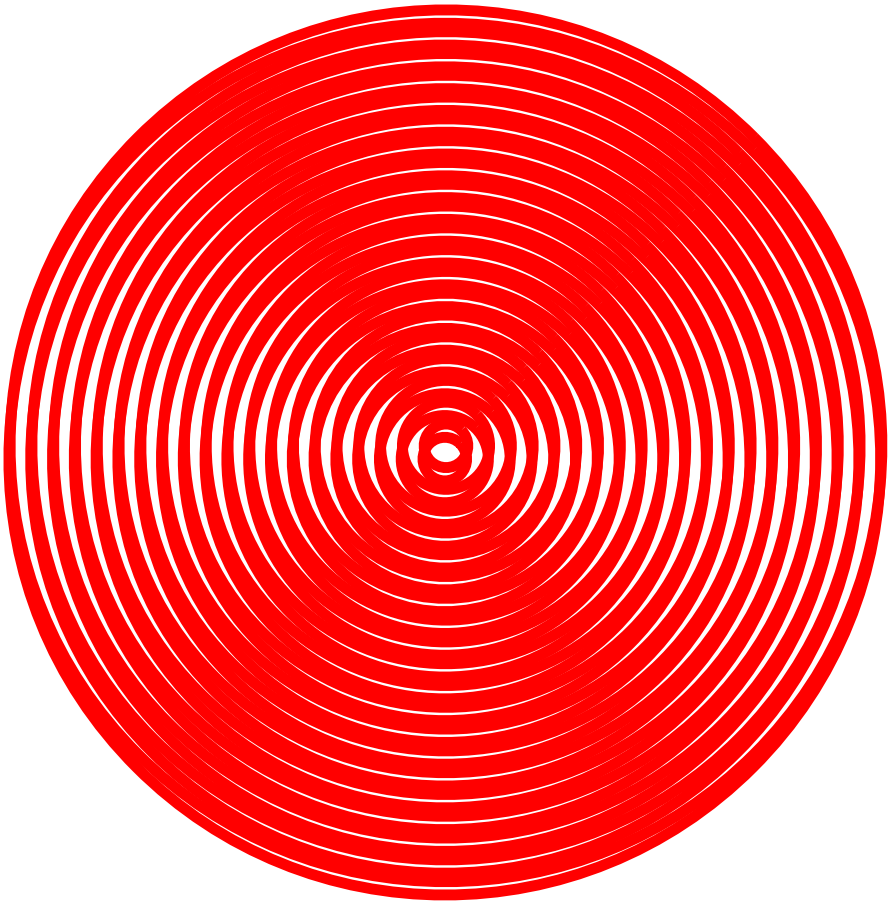


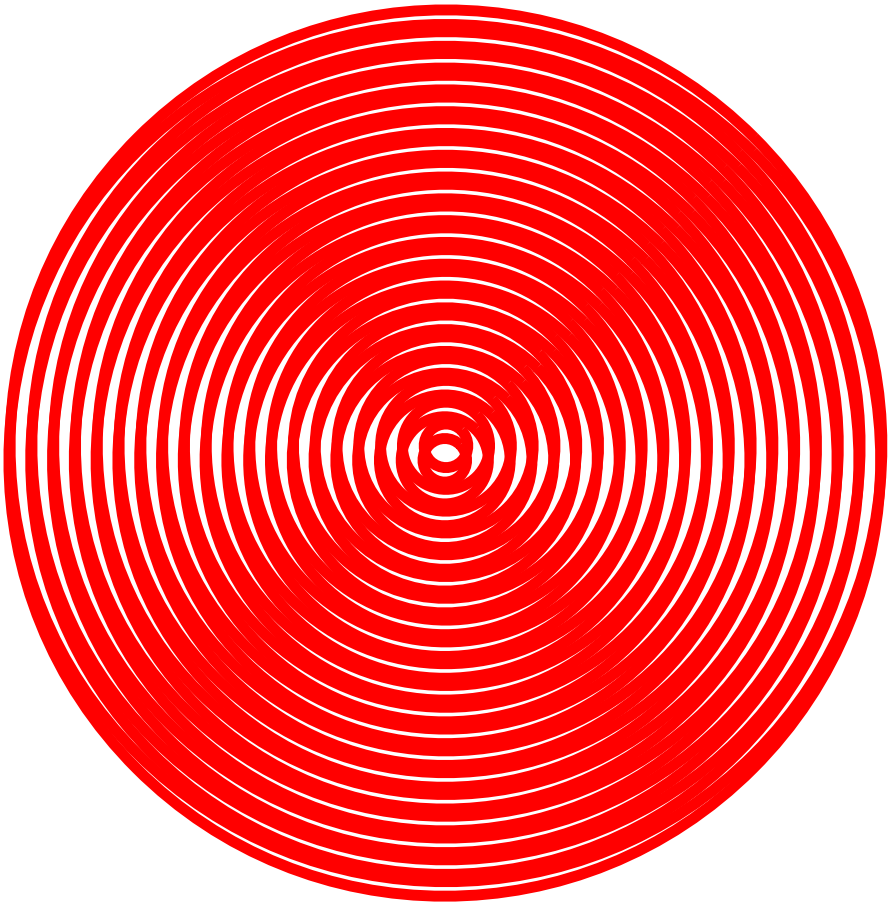


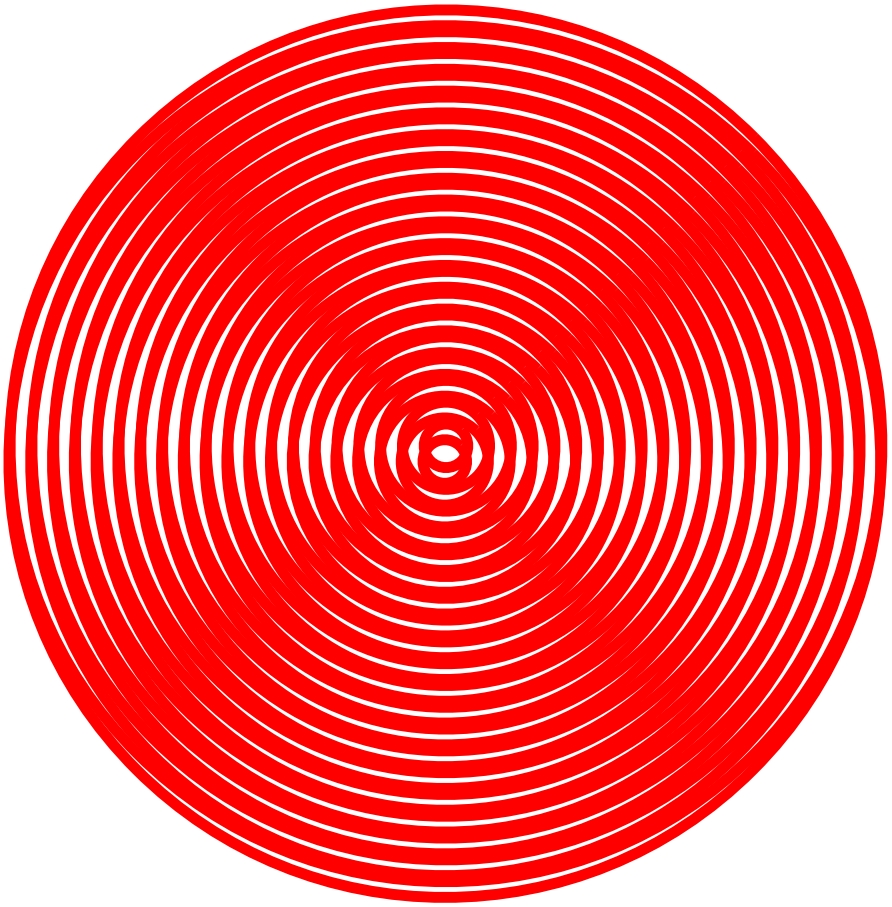


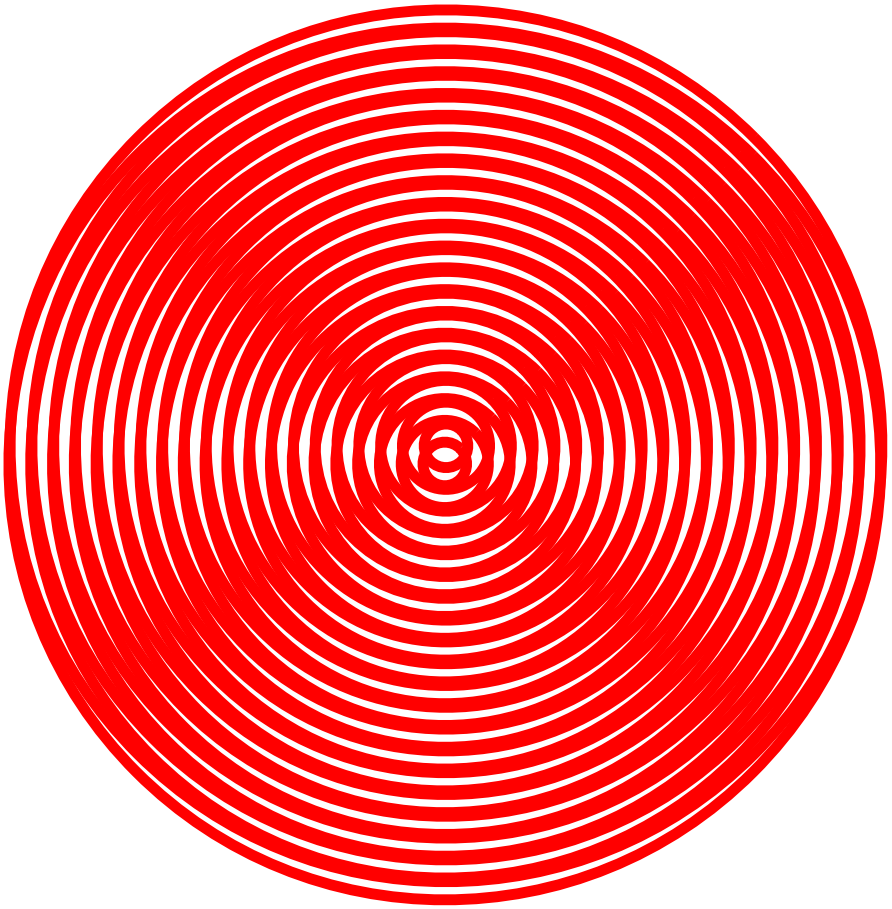


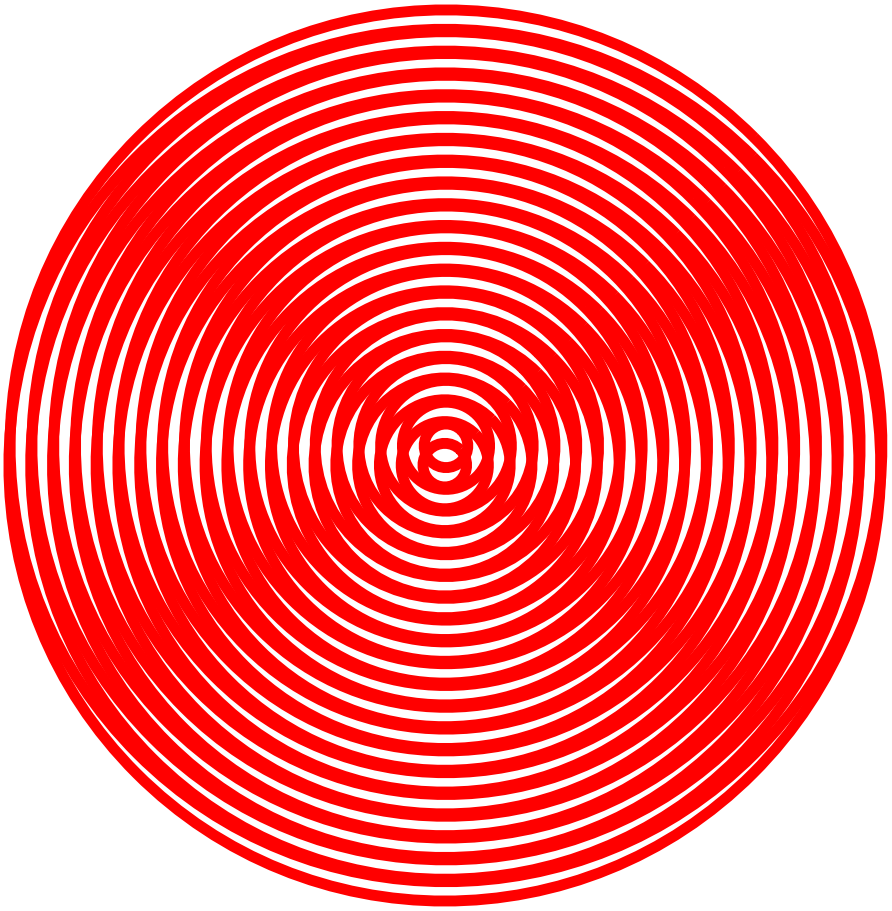


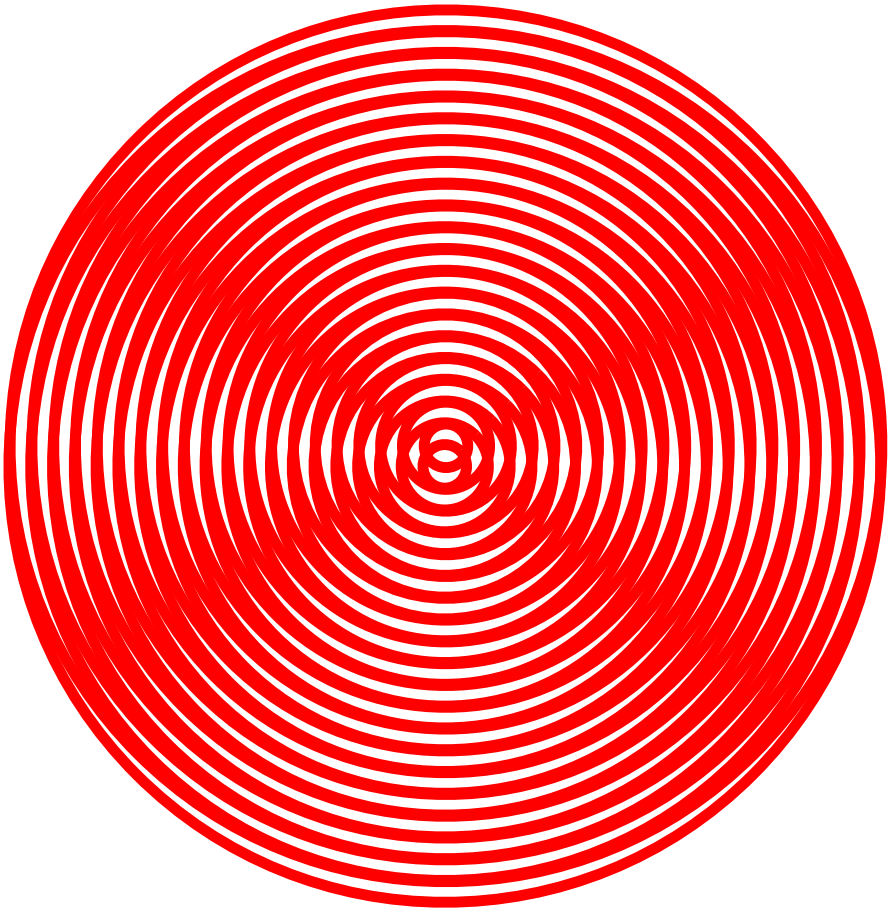


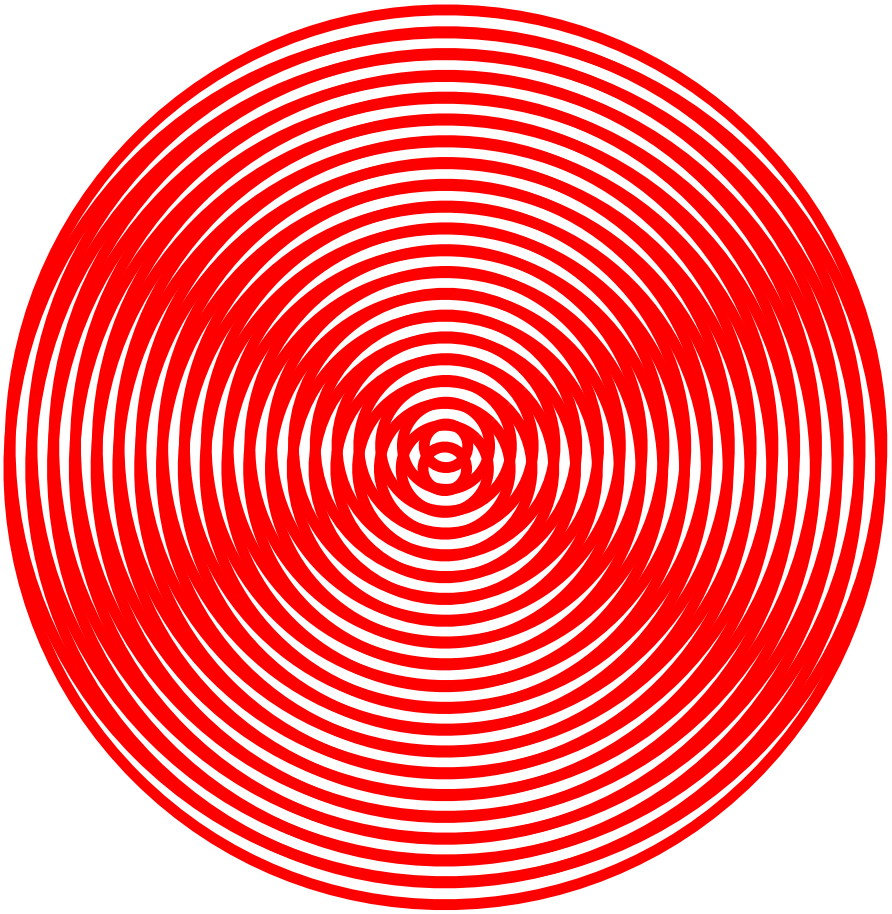


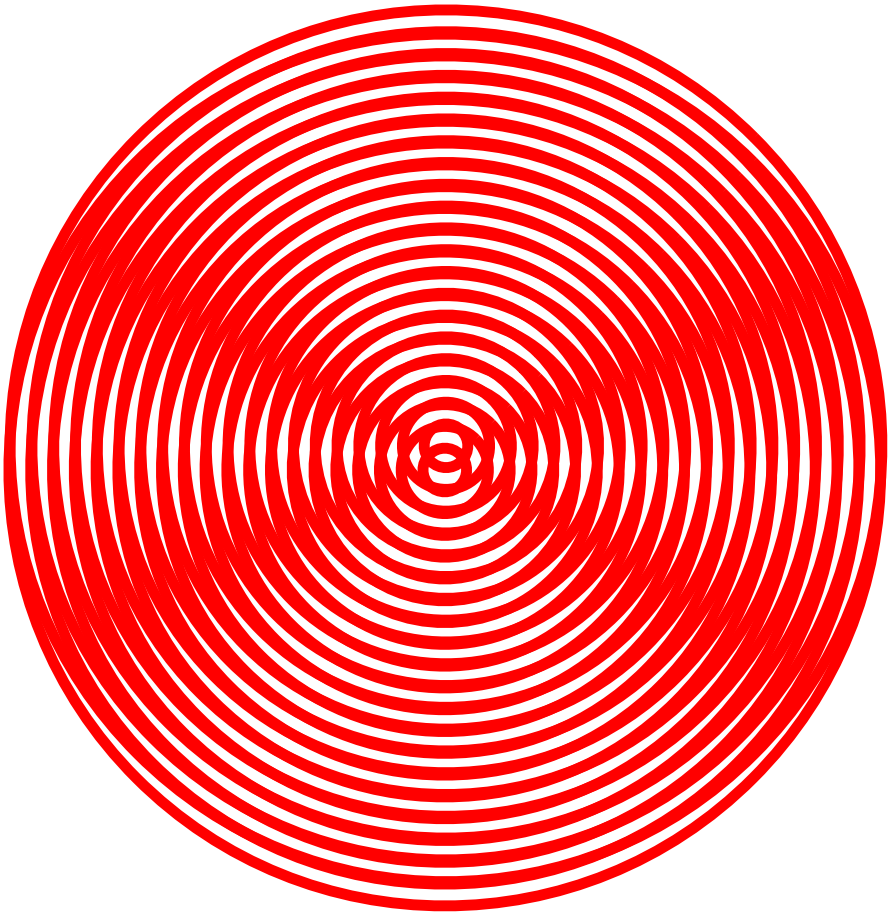


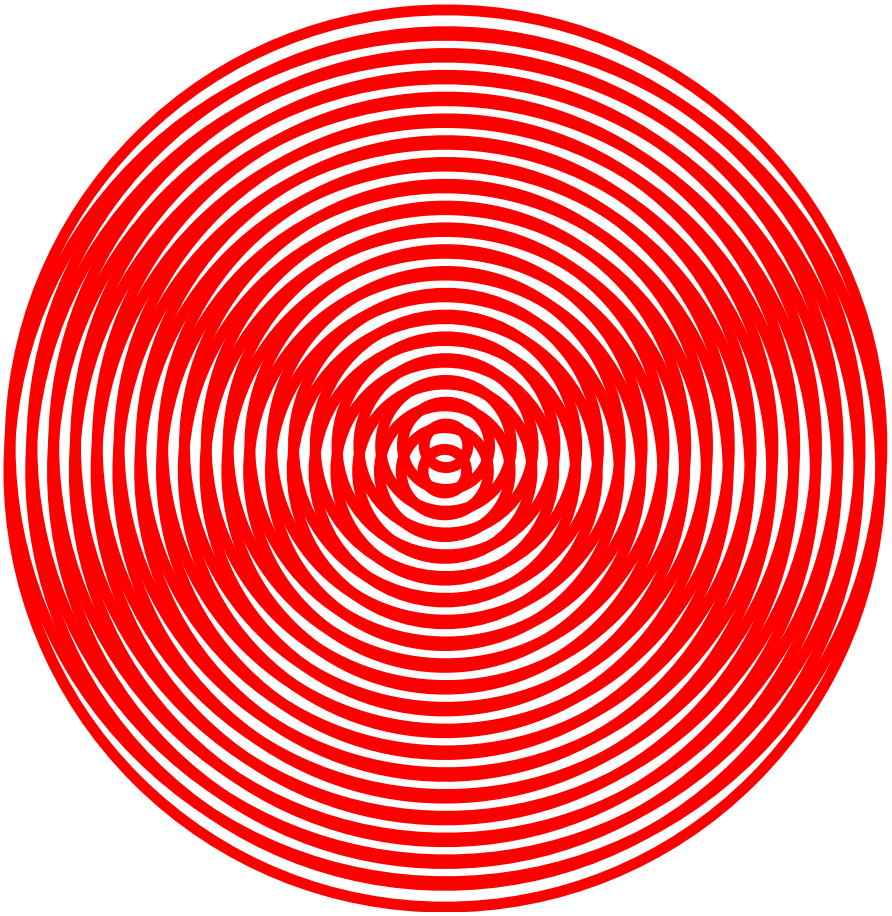


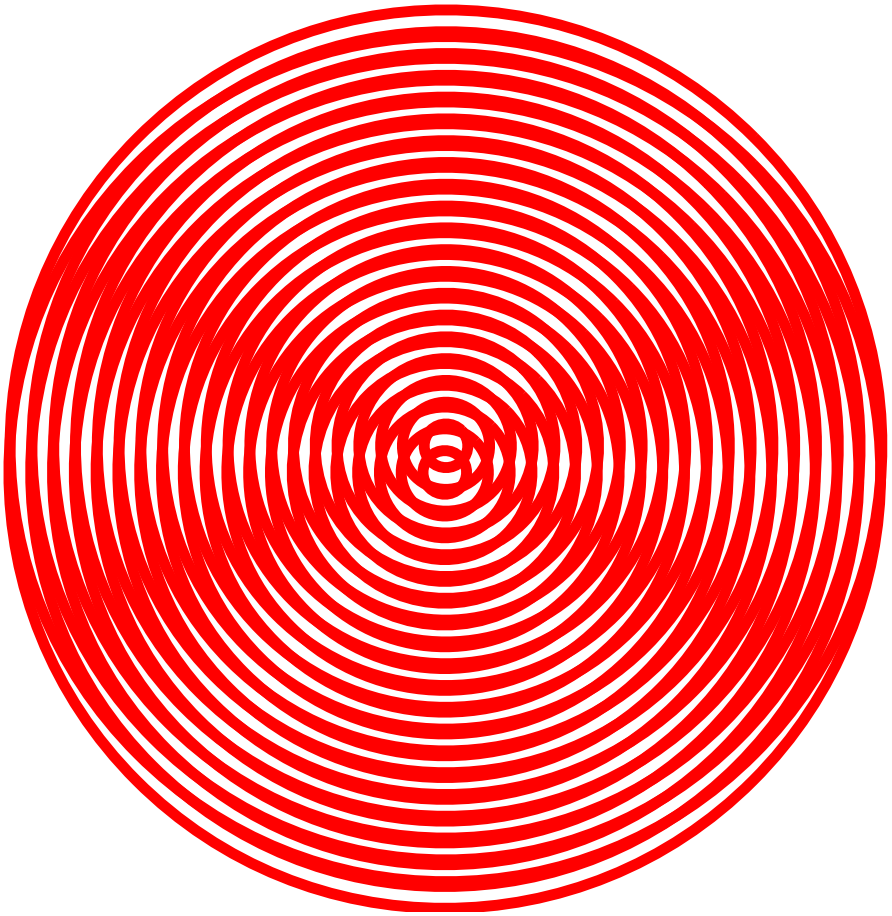


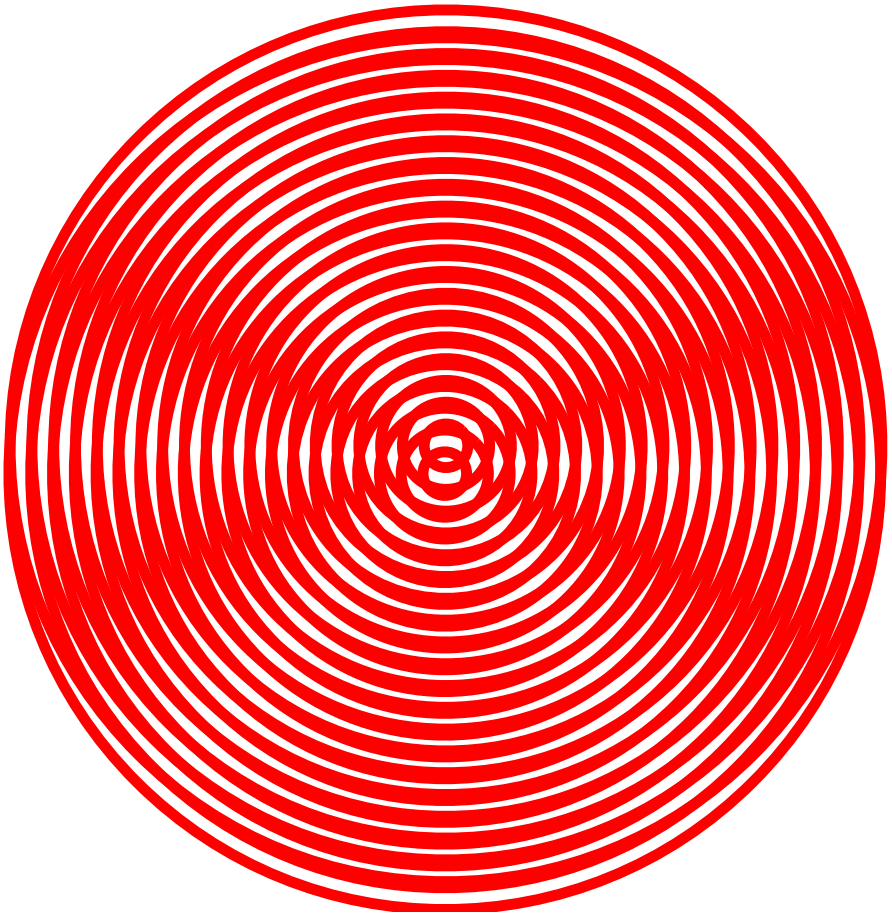


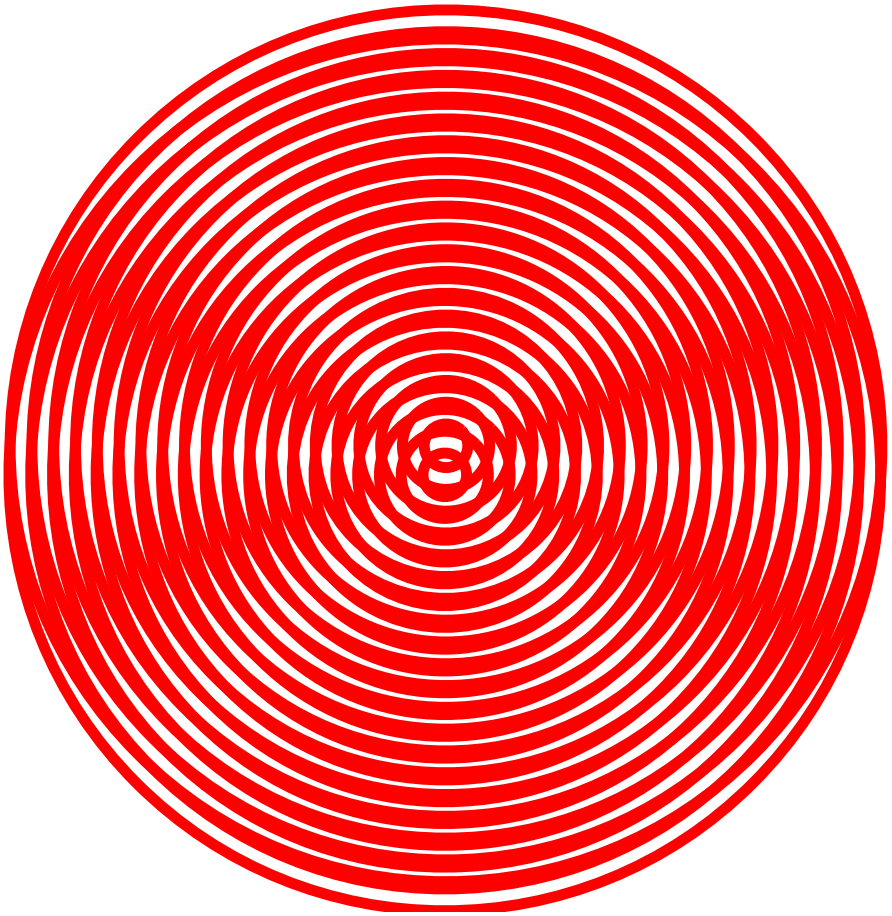


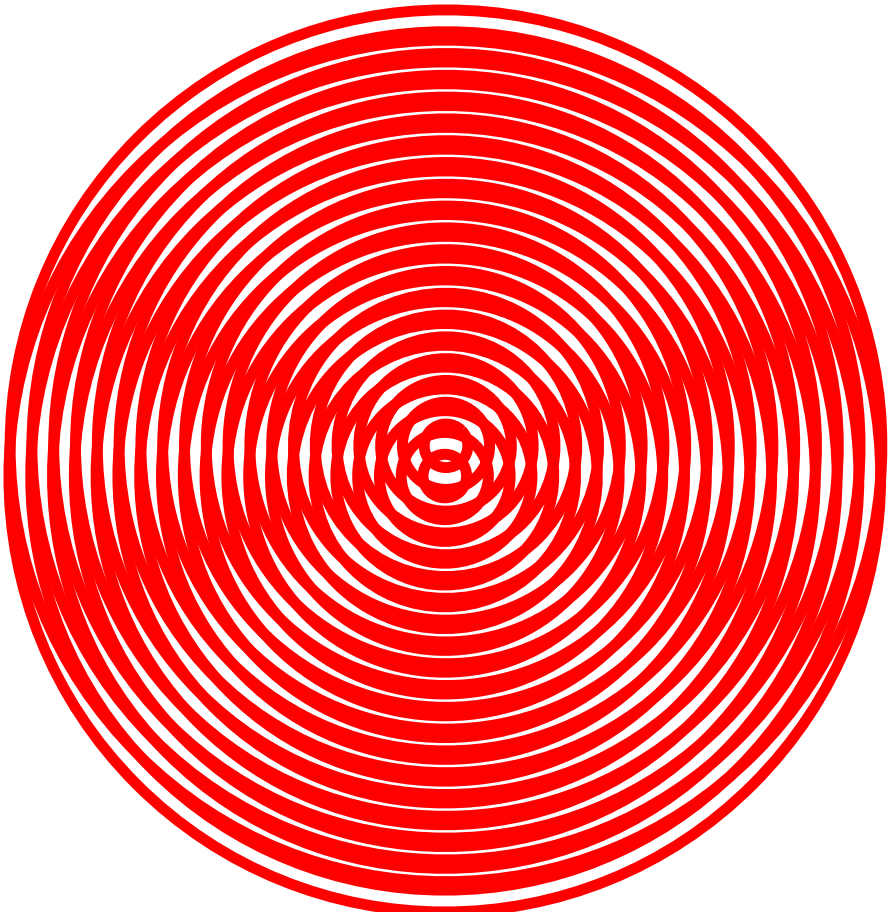


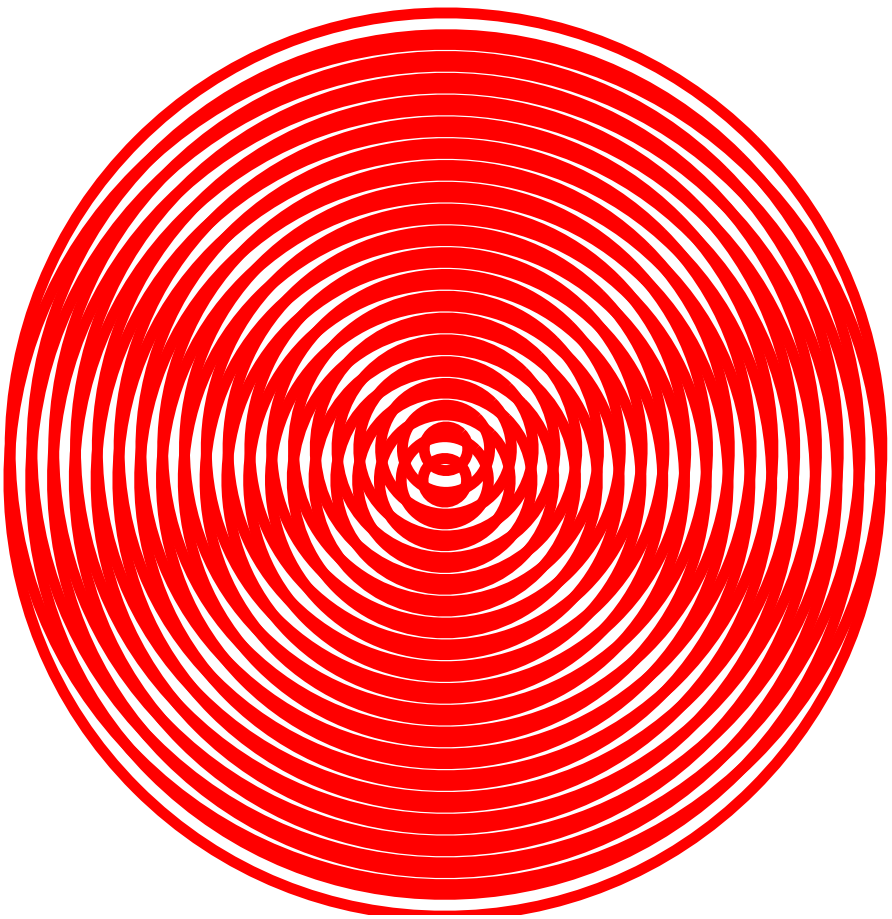


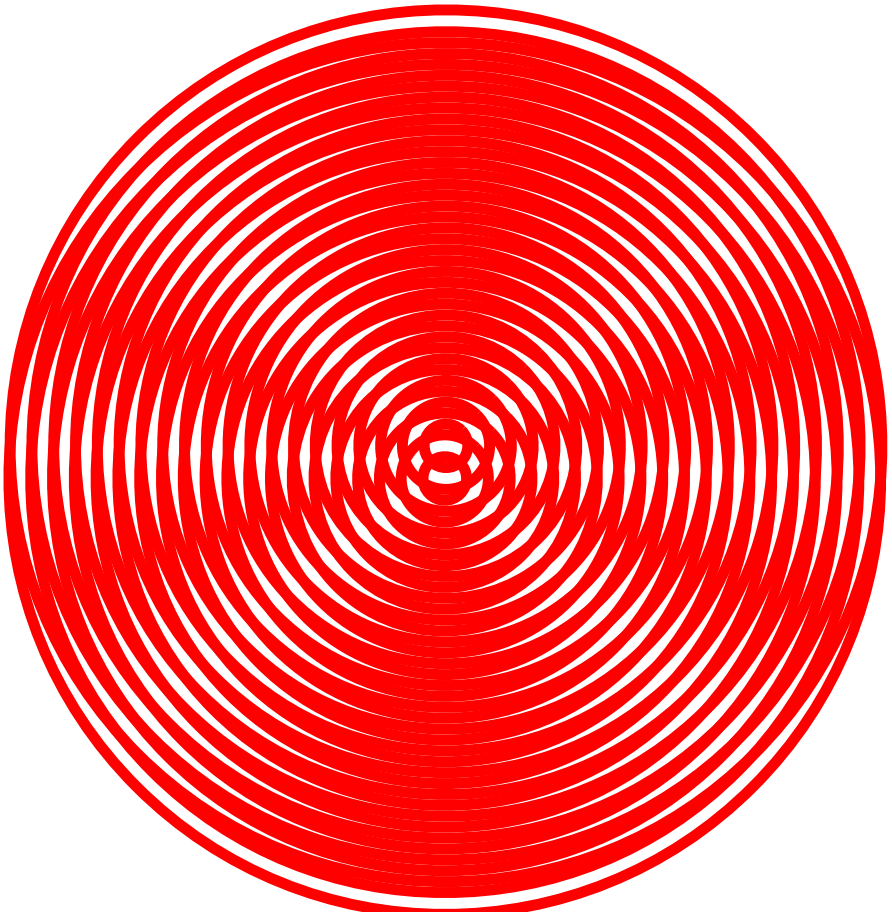


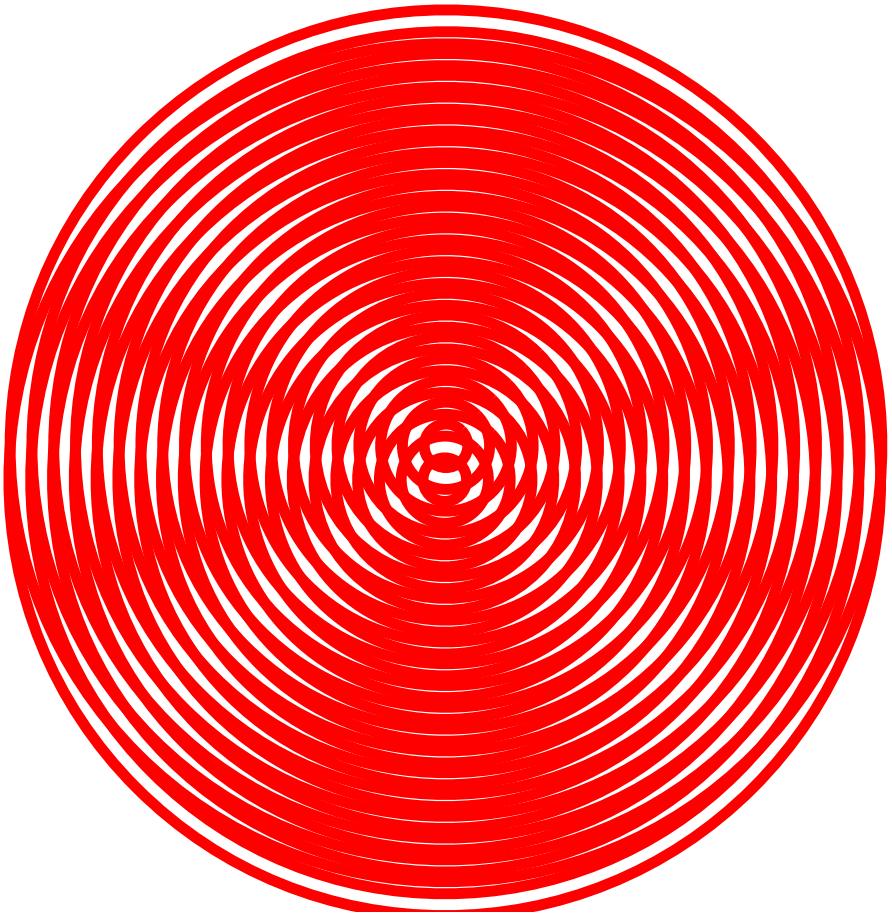


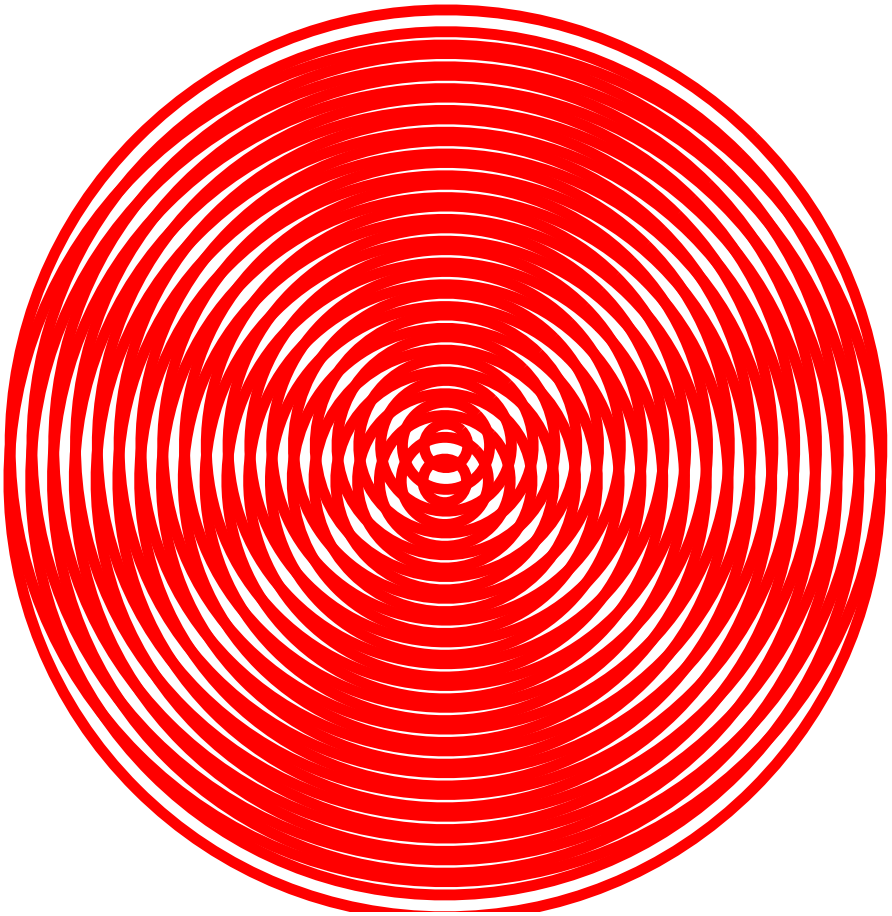


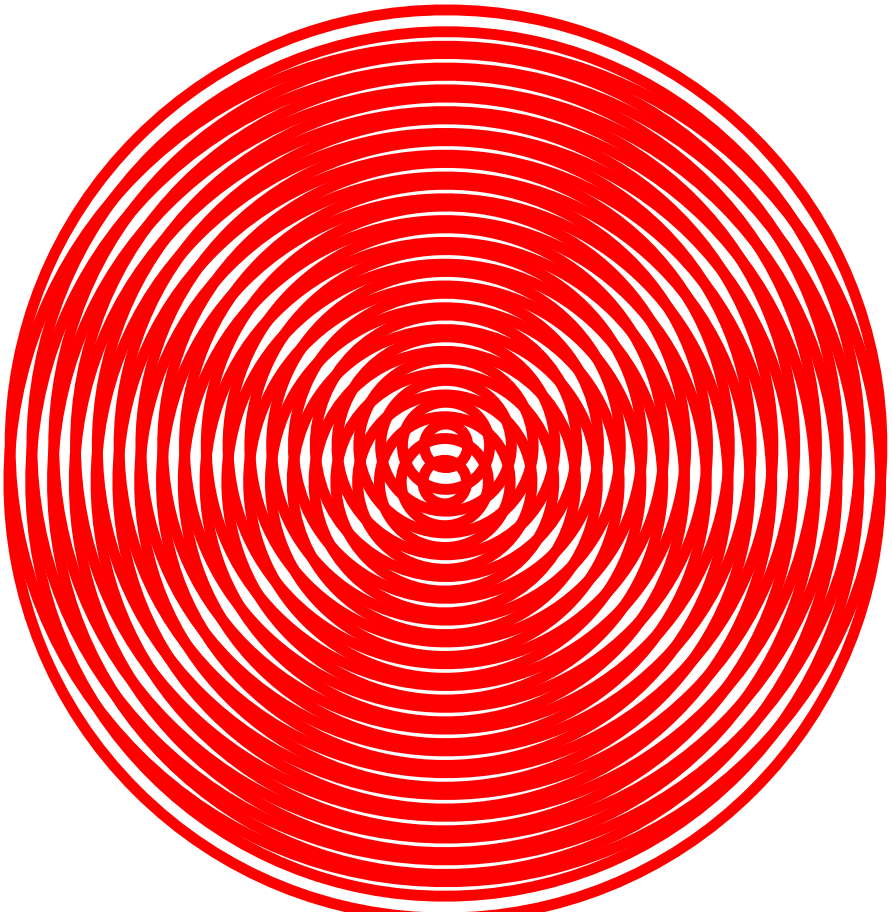


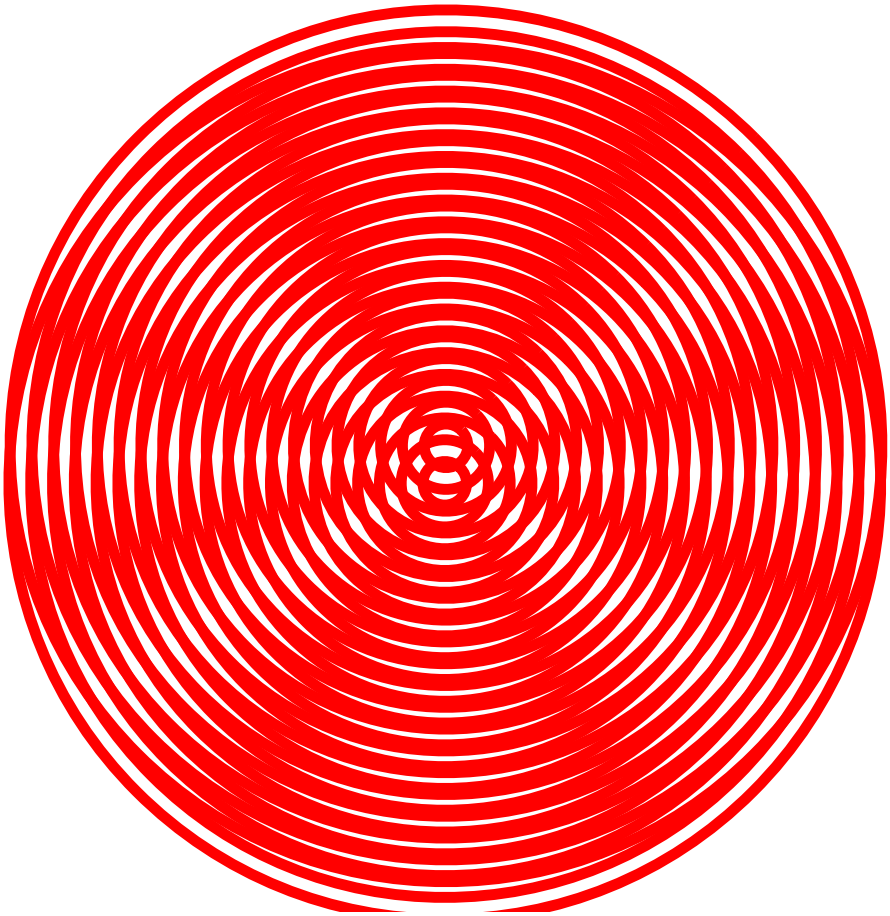


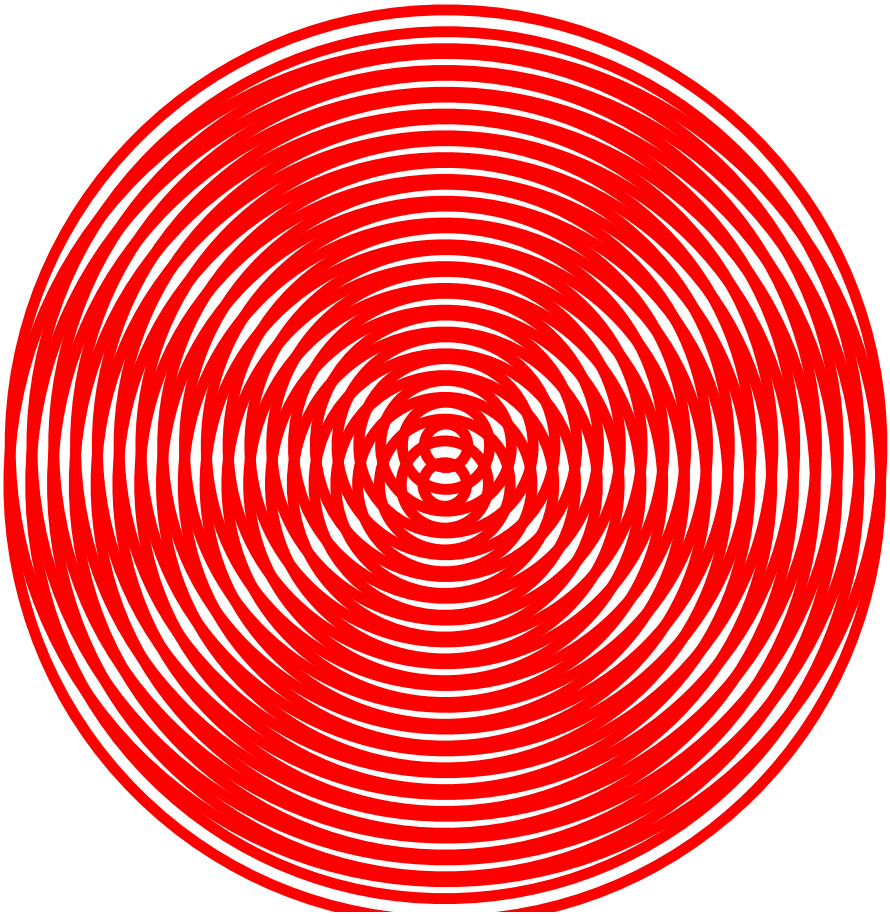


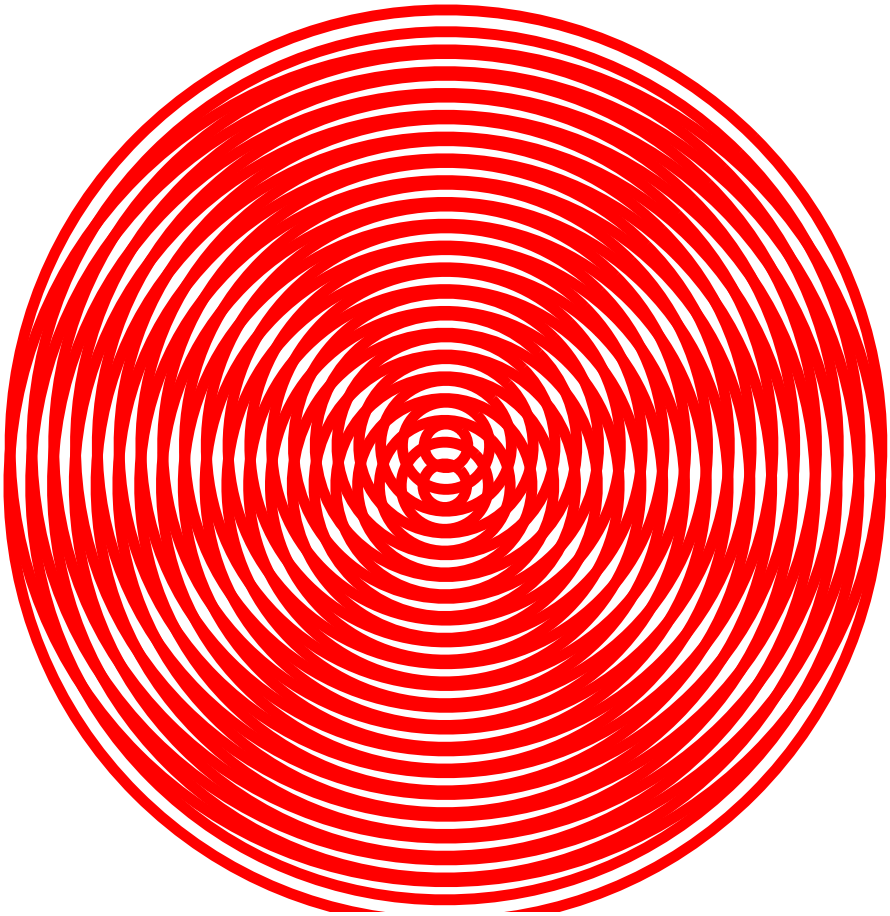


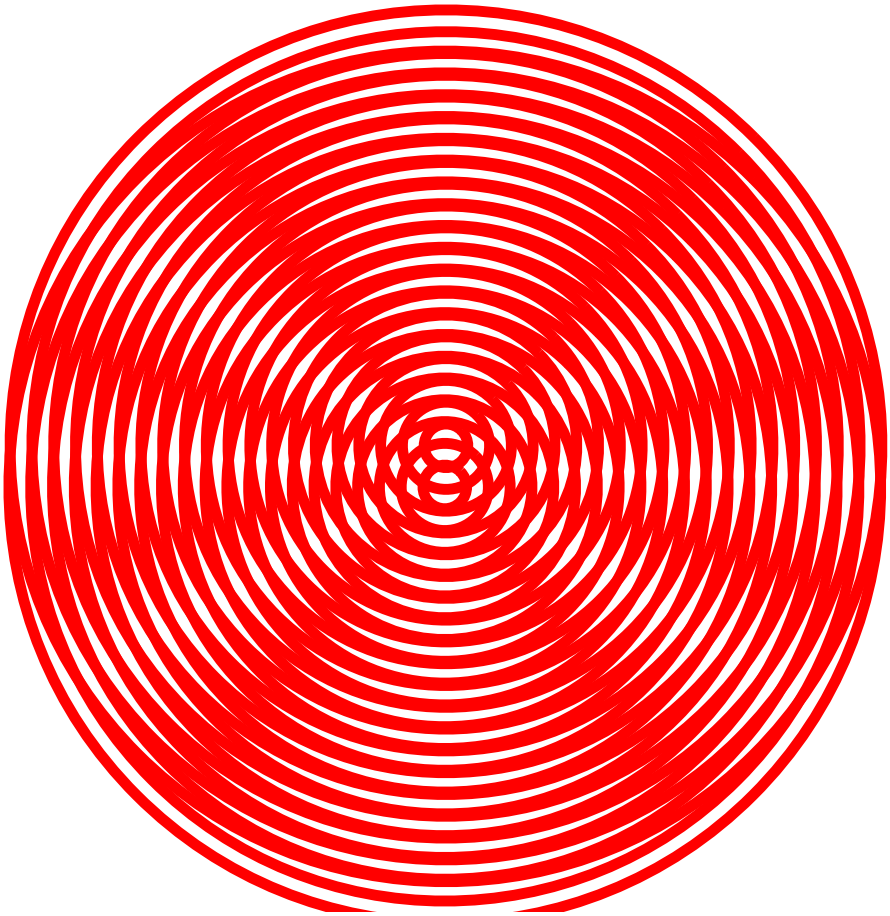


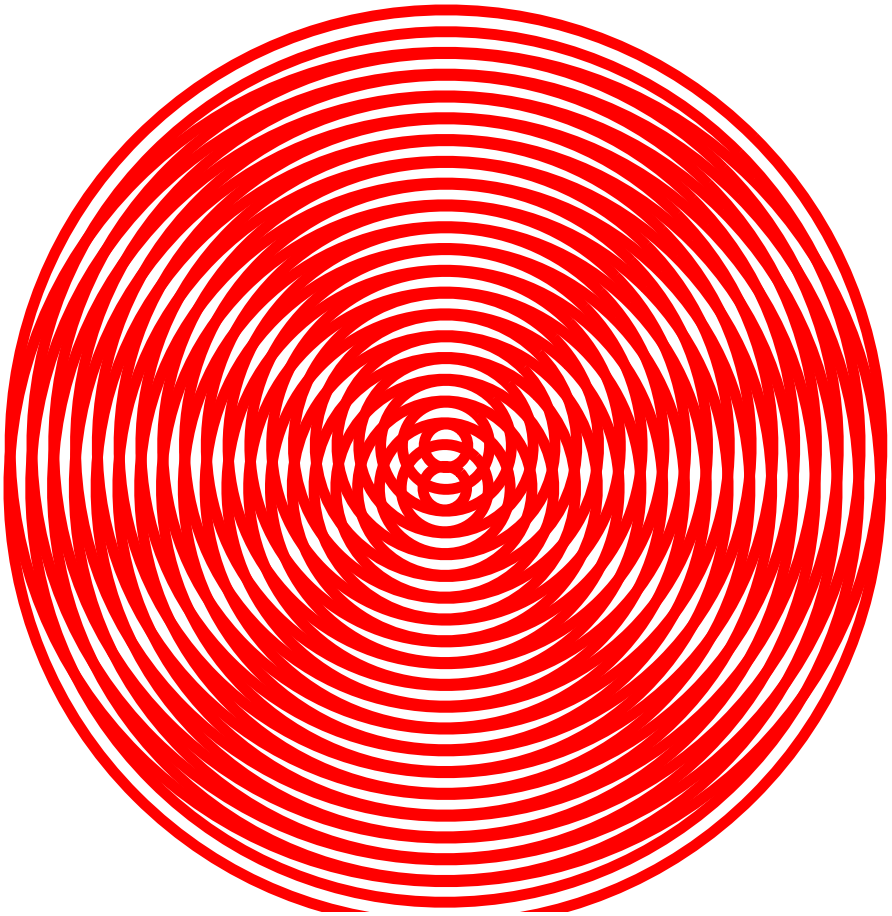


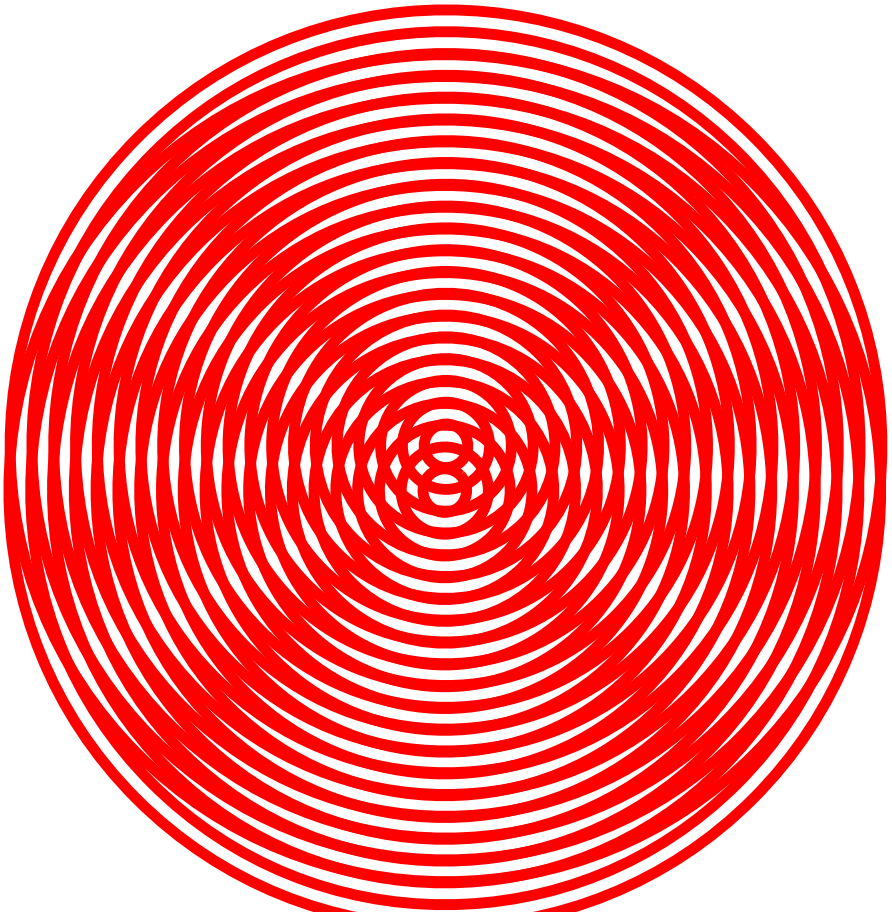


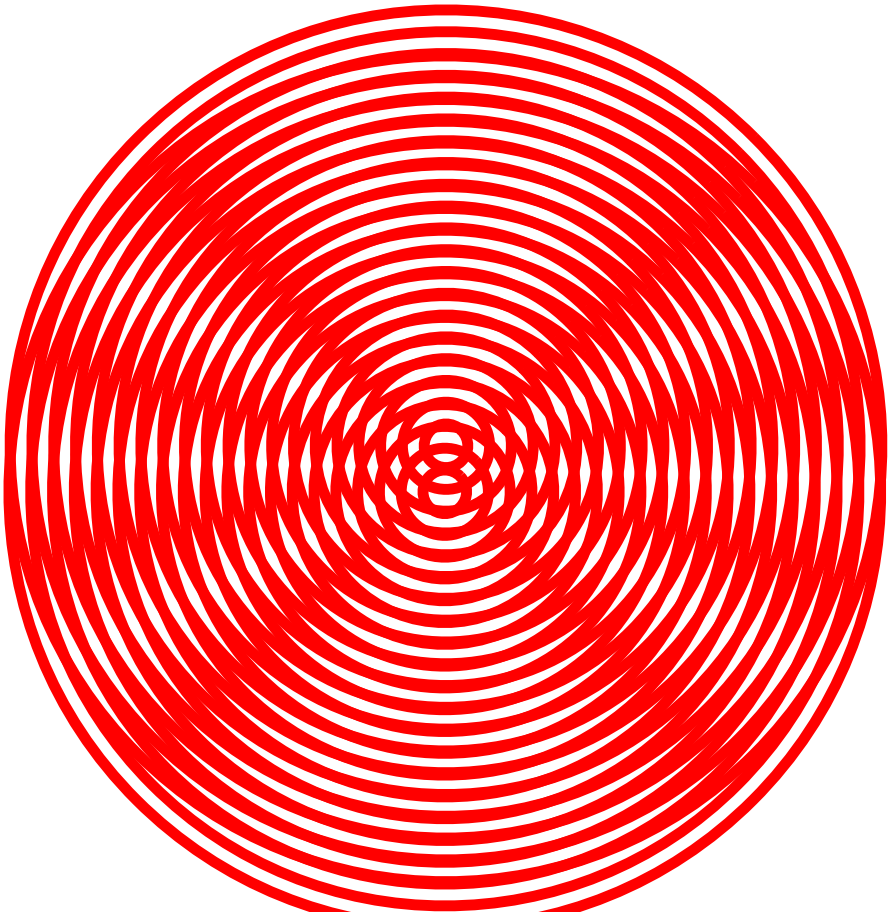


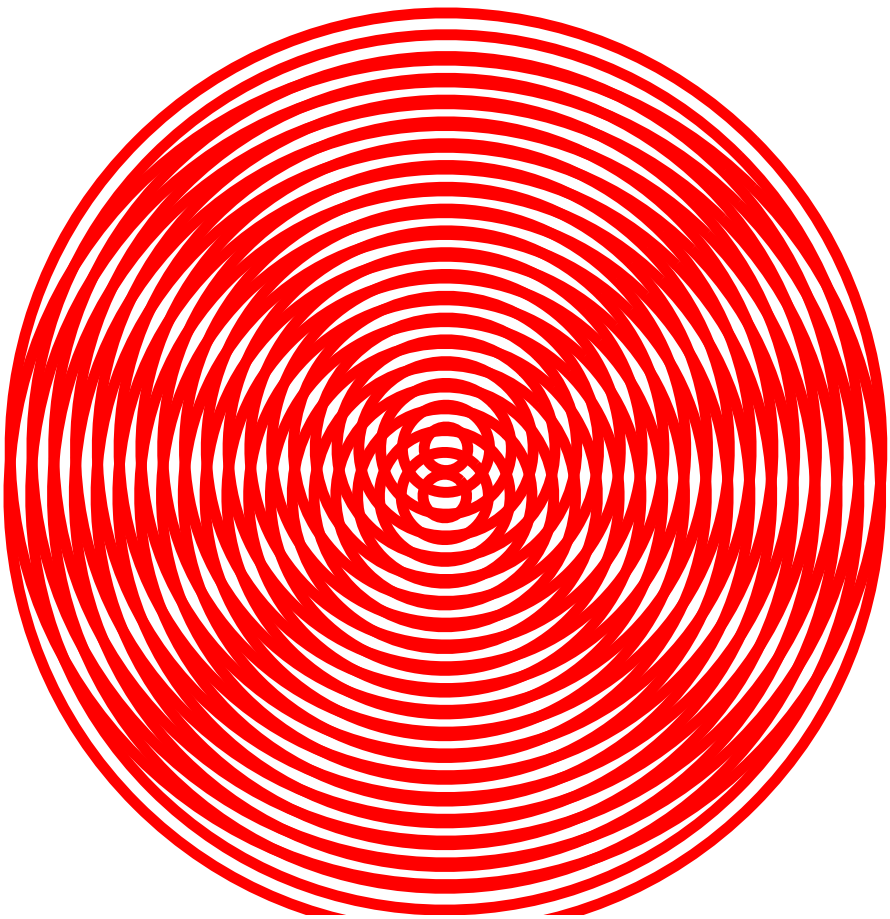


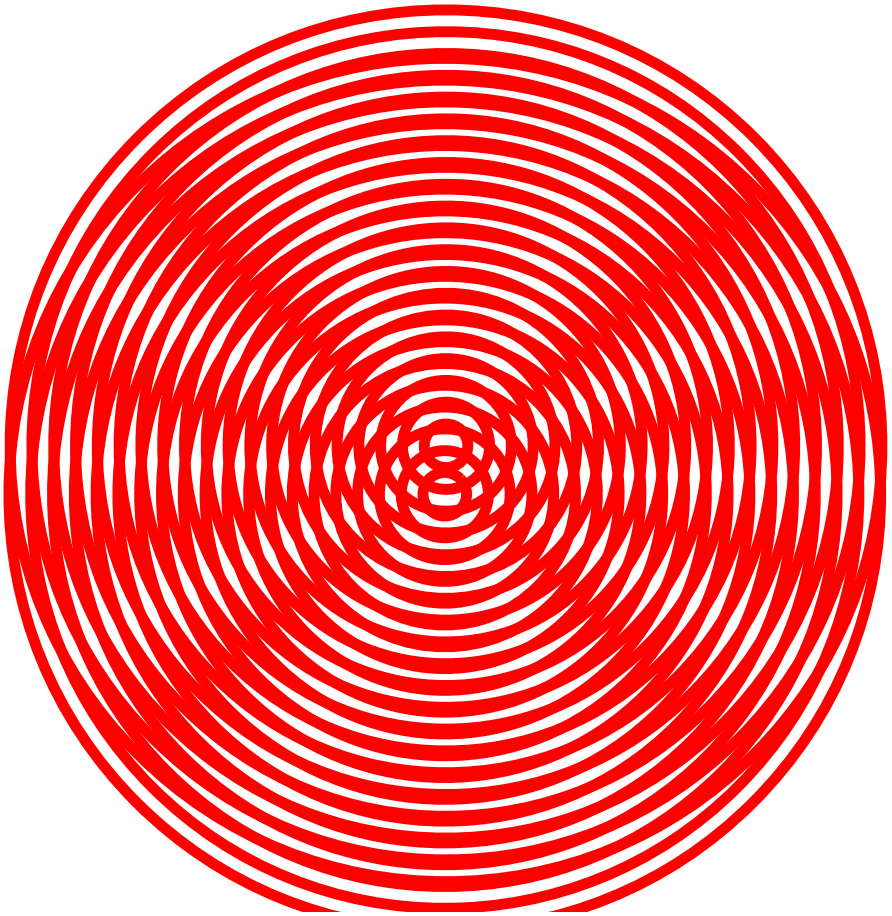


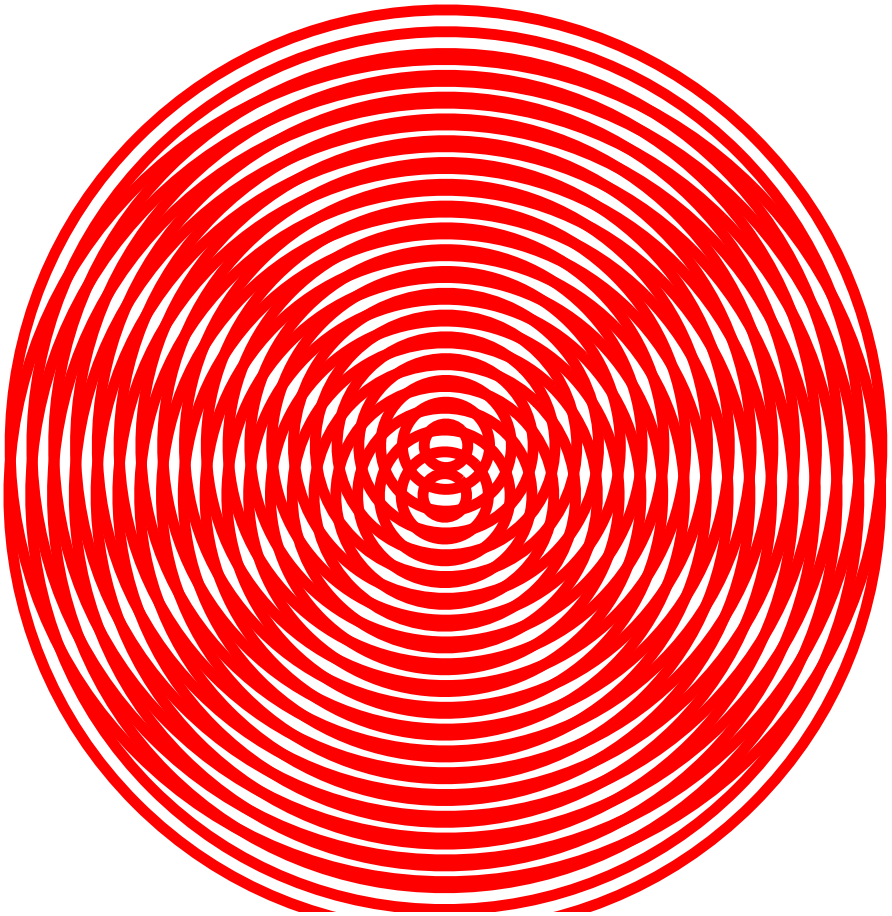


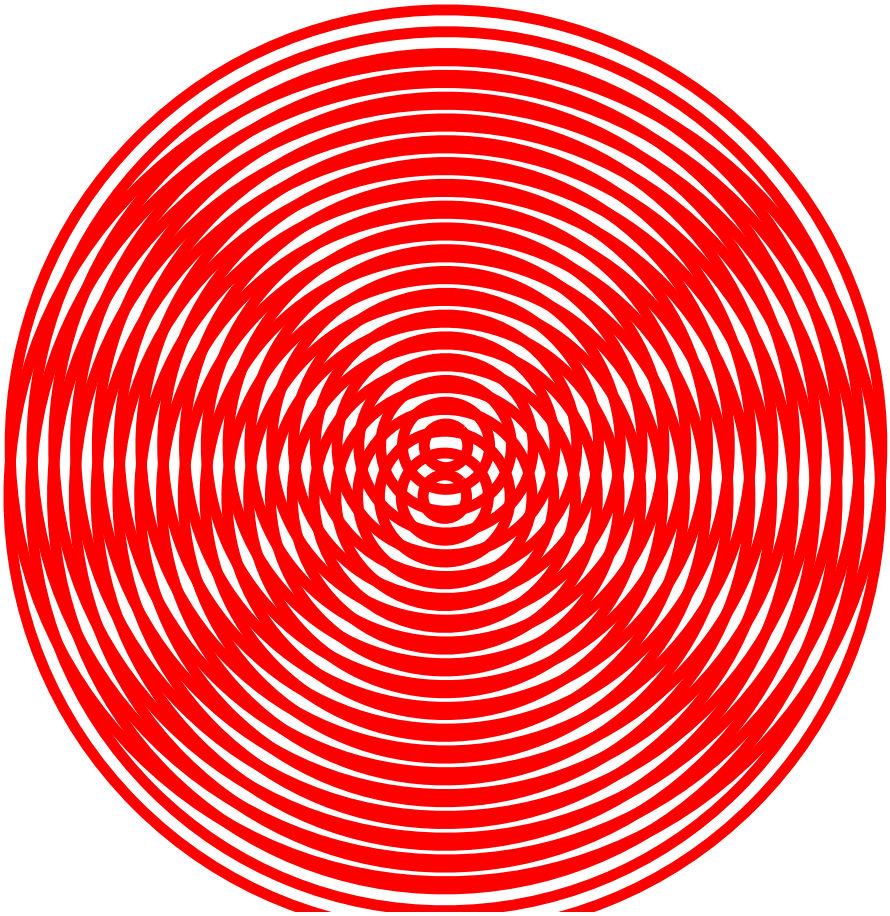


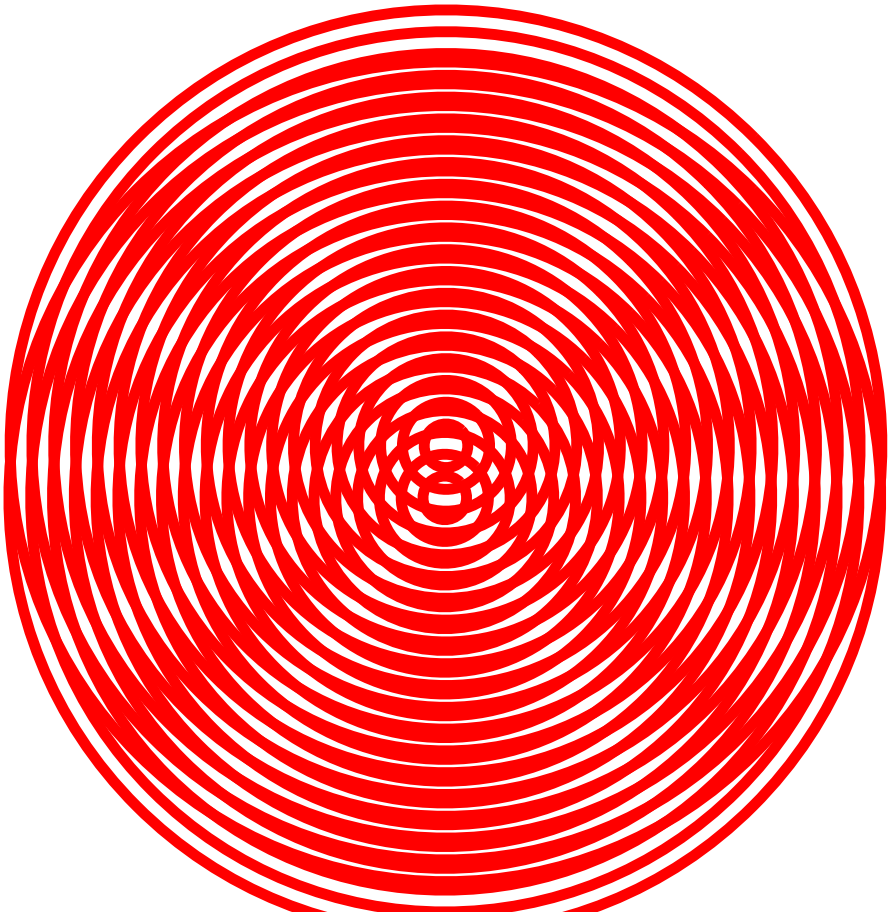


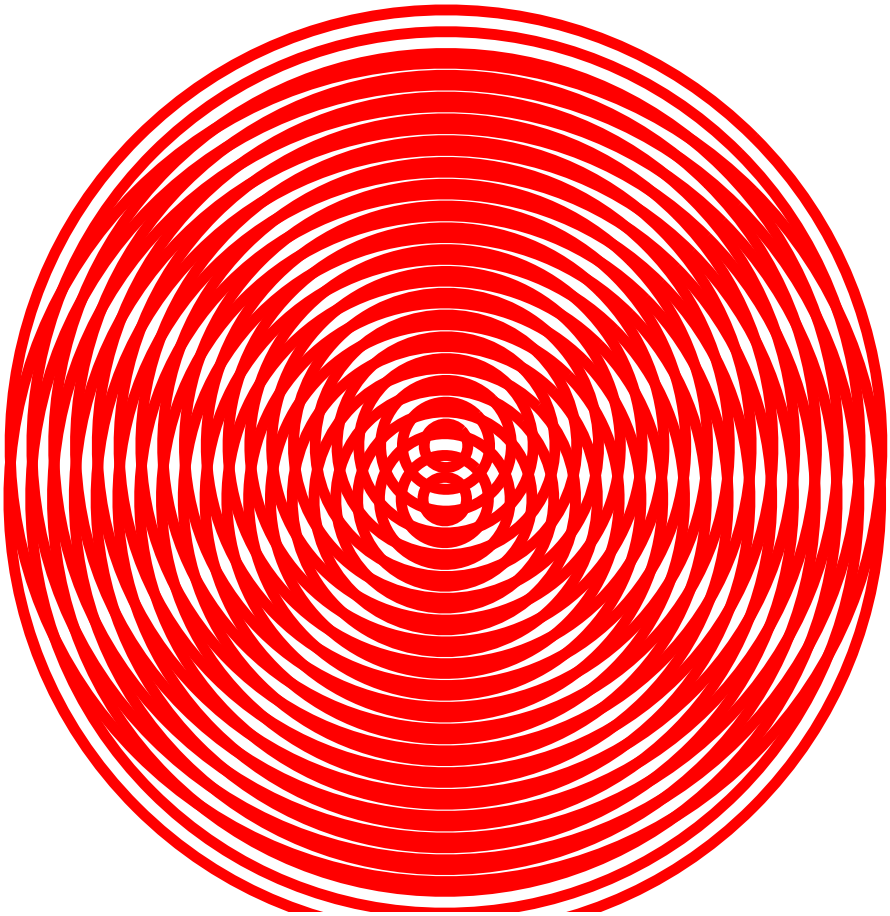


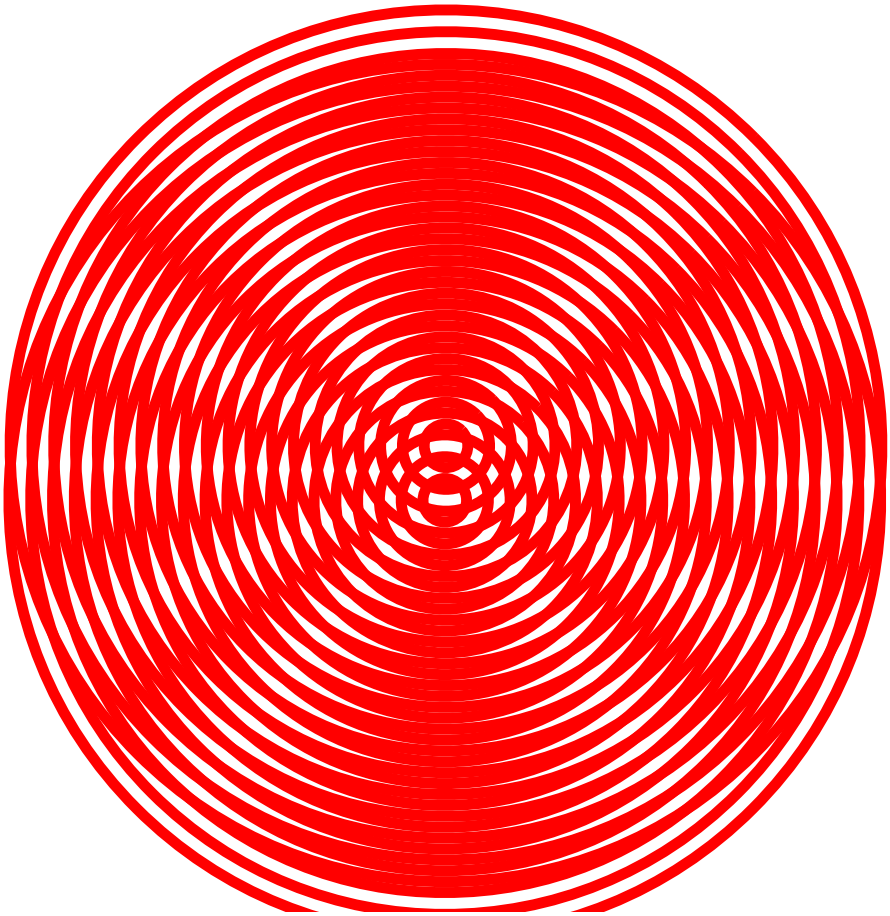




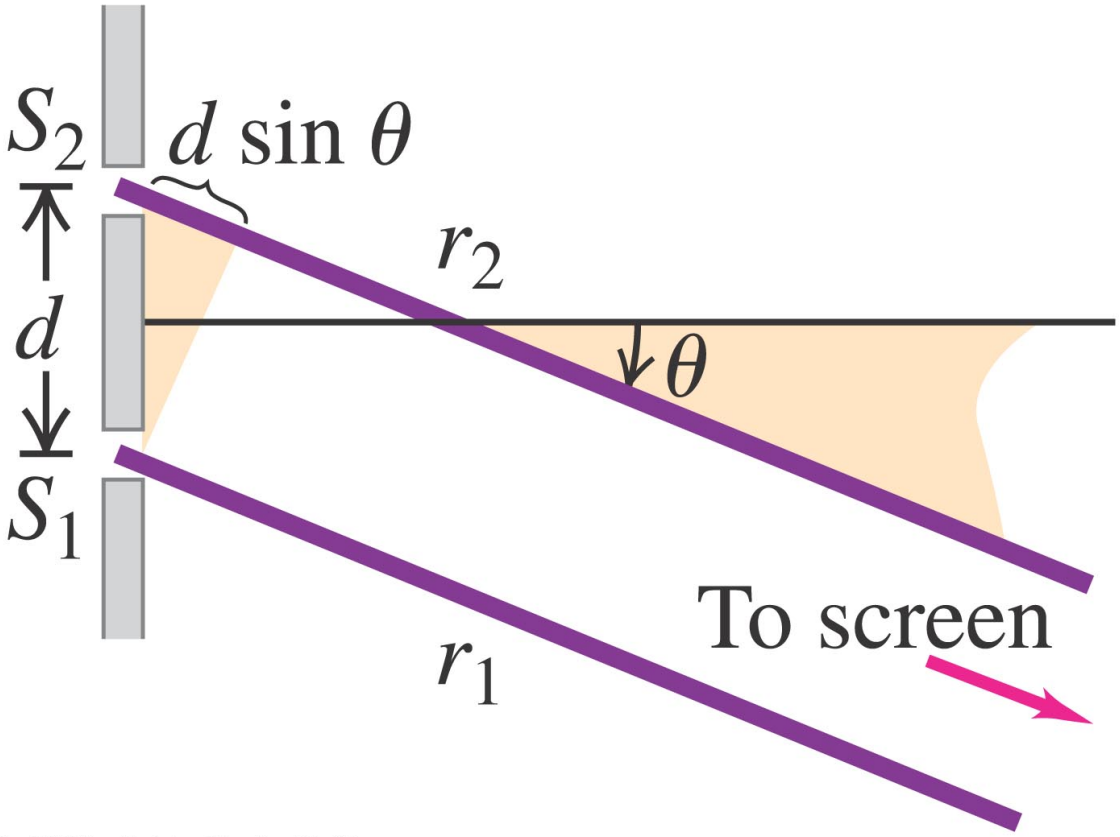








Unnumbered Figure 35.2



In Young's experiment, coherent light passing through two slits (S_1 and S_2) produces a pattern of dark and bright areas on a distant screen. If the wavelength of the light is increased, how does the pattern change?

A. The bright areas move closer together.

B. The bright areas move farther apart.

C. The spacing between bright areas remains the same, but the color changes.

D. any of the above, depending on circumstances

E. none of the above

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E. none of the above

Unnumbered Figure 35.3

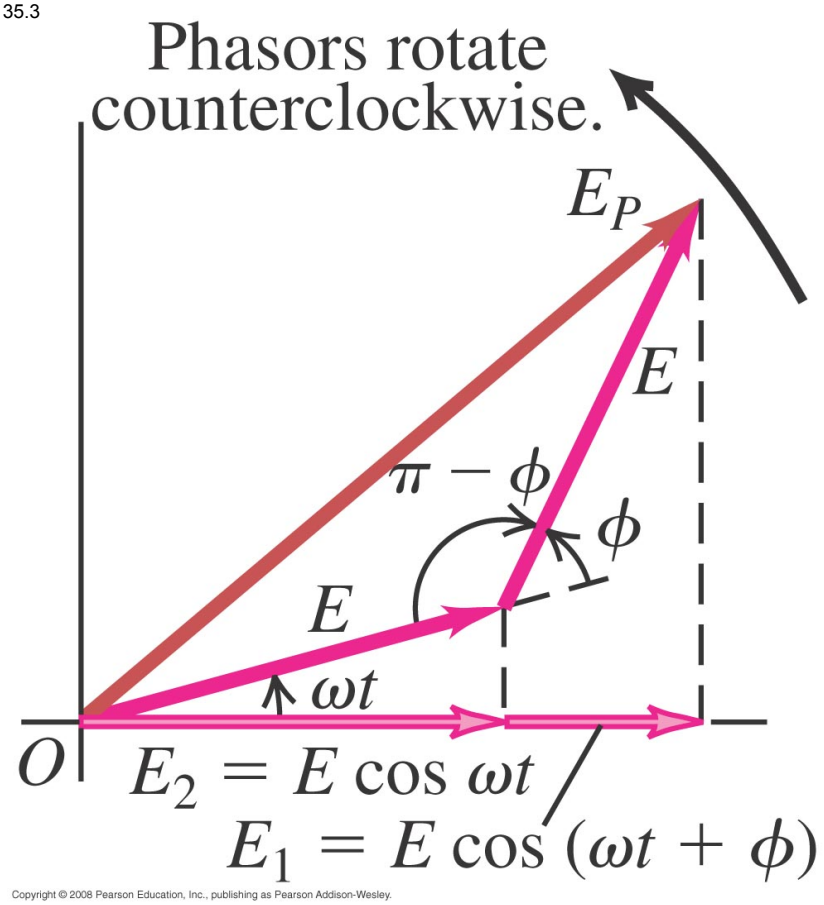


Figure 35.12

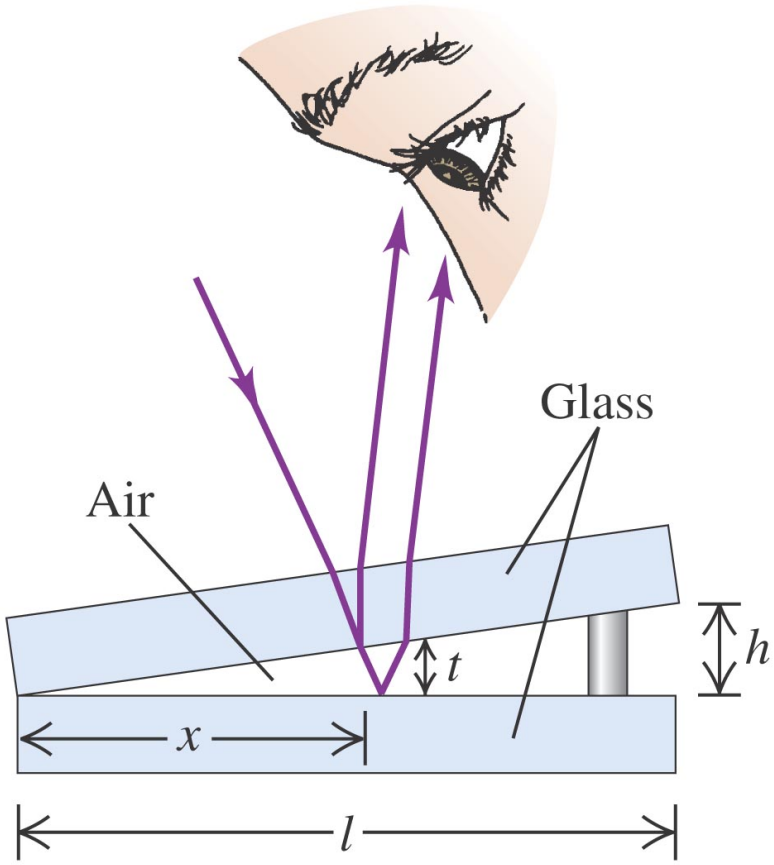
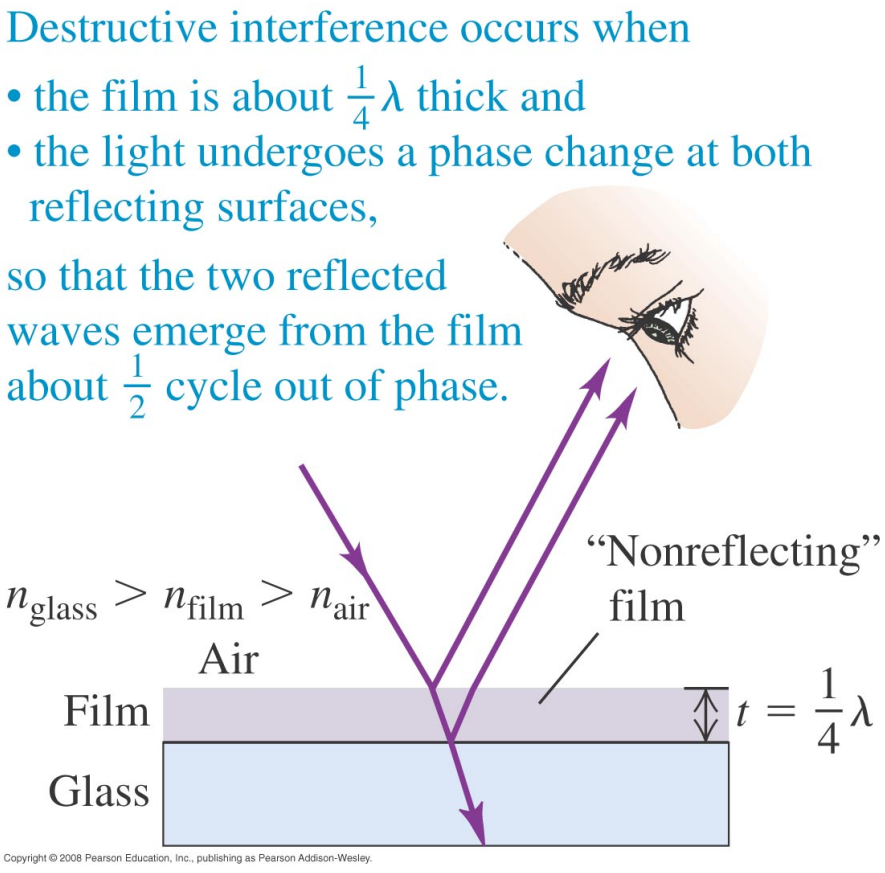


Figure 35.19



Clicker Question

The laser pointer I use in class operates at a wavelength of 670 nm with a power of 0.500 mW spread uniformly over a circle 1.20 mm in diameter. It is also waterproof.

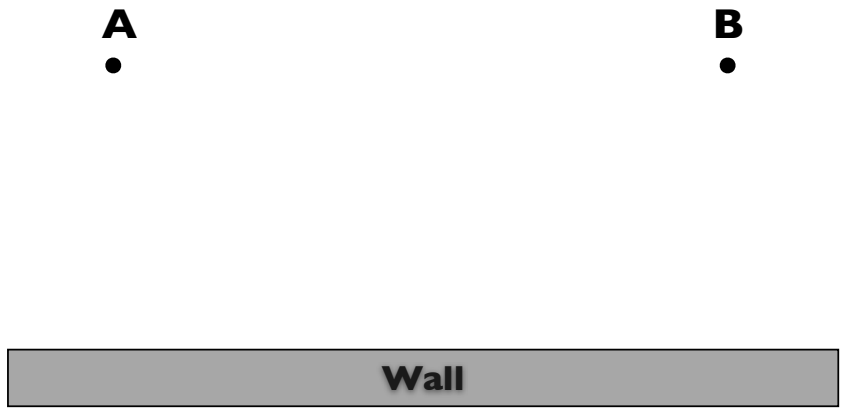
Assuming my laser pointer works in air and in water, fill in the following table. Water has an index of refraction of n=1.33

The laser pointer I use in class operates at a wavelength of 670 nm with a power of 0.500 mW spread uniformly over a circle 1.20 mm in diameter. It is also waterproof.

Assuming my laser pointer works in air and in water, fill in the following table. Water has an index of refraction of n=1.33

	Air	Water
Wavelength, λ	670 nm	$\lambda = 670\ nm/n = 504\ nm$
Frequency, f	$f\ \lambda=c,\ f=c/\lambda=4.48\times10^{14}\ Hz$	$f\ \lambda=c,\ f=c/\lambda=4.48\times10^{14}\ Hz$
Angular Frequency, ω	$\omega=2\pi f=2.81\times10^{15}\ s^{-1}$	$\omega=2\pi f=2.81\times10^{15}\ s^{-1}$
Wavenumber, k	$k=2\pi/\lambda=9.38\times10^{6}\ m^{-1}$	$k=2\pi n/\lambda=1.25\times10^{7}\ m^{-1}$
Period, T	$T=1/f=2.23\times10^{-15}\ s$	$T=1/f=2.23\times10^{-15}\ s$

(10 points) Sprinters must run (at a constant velocity) from point A to point B but must touch the wall at some point between starting and finishing the race. Accurately sketch the quickest path the sprinters should take under these rules.



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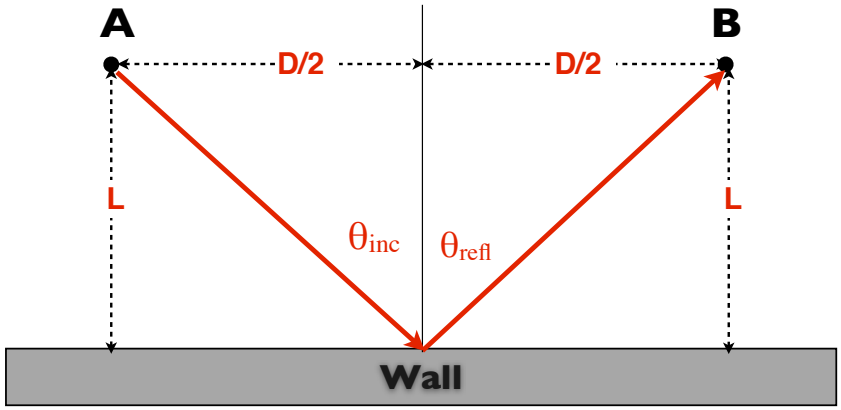
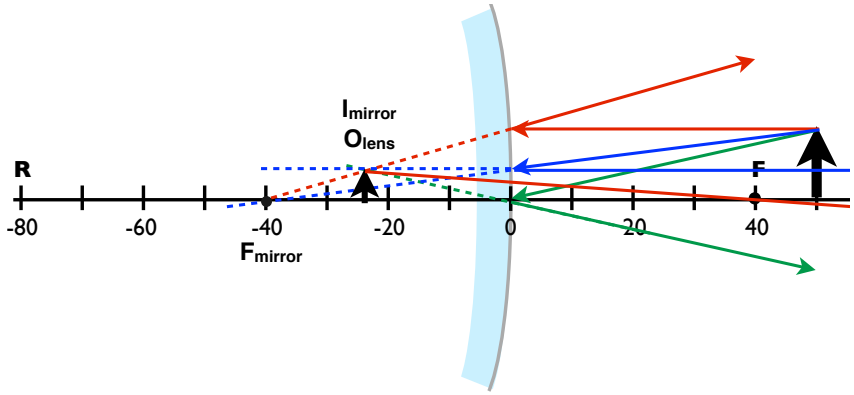


An optical system comprises in turn, from left to right: a convex mirror of radius 80 cm, an erect object 20 mm high, a lens of focal length +30 cm, and an observer. The object is between the lens and the mirror, 20 cm from the lens and 50 cm from the mirror. The observer views the image that is formed first by reflection and then by refraction.



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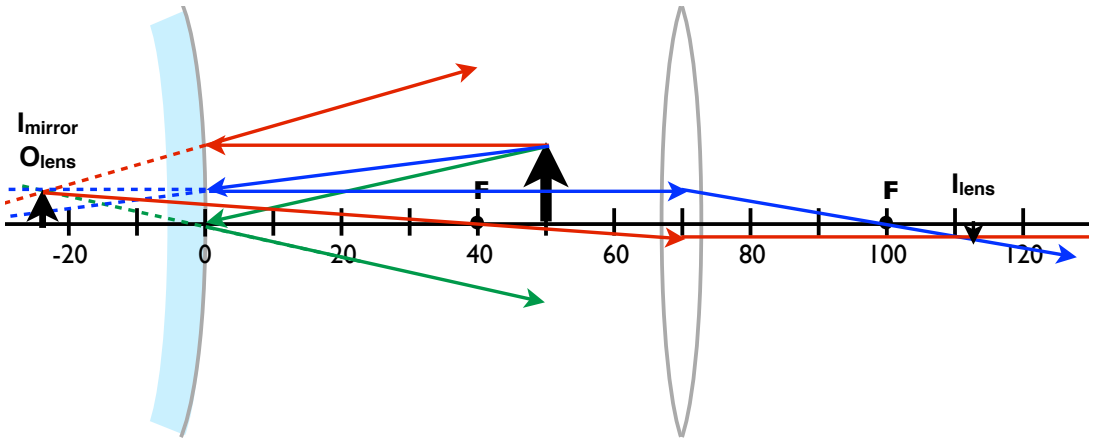

Clicker Question

At a given time, an electromagnetic plane wave propagating in the negative z-direction is polarized in the positive y direction. What is the direction of the magnetic field? Assume a right-handed coordinate system.

A) +X

B) -X

C) +Y

D) -Y

E) +Z

Clicker Question

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A) +X

B) -X

C) +Y

D) -Y

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Clicker Question

Light travel from a high index material to a lower index material. Can the Brewster angle occur simultaneously with total internal reflection?

A) Yes

B) No

C) It can be either

Light travel from a high index material to a lower index material. Is the Brewster (or polarizing) angle of incidence greater than or less than the critical angle of incidence for total internal reflection?

DEFINITIONS :

$$\tan(\theta_P) = \frac{n_2}{n_1} = \sin(\theta_C)$$

$$\tan(\theta) = \frac{\sin(\theta)}{\cos(\theta)} > \sin(\theta),\ \arctan\left(\frac{n_2}{n_1}\right) < \arcsin\left(\frac{n_2}{n_1}\right)$$

Clicker Question

Light travel from a high index material to a lower index material. Can the Brewster angle occur simultaneously with total internal reflection?

A) Yes

B) No

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Clicker Question

Light travel from a high index material to a lower index material. Can the Brewster angle occur simultaneously with total internal reflection?

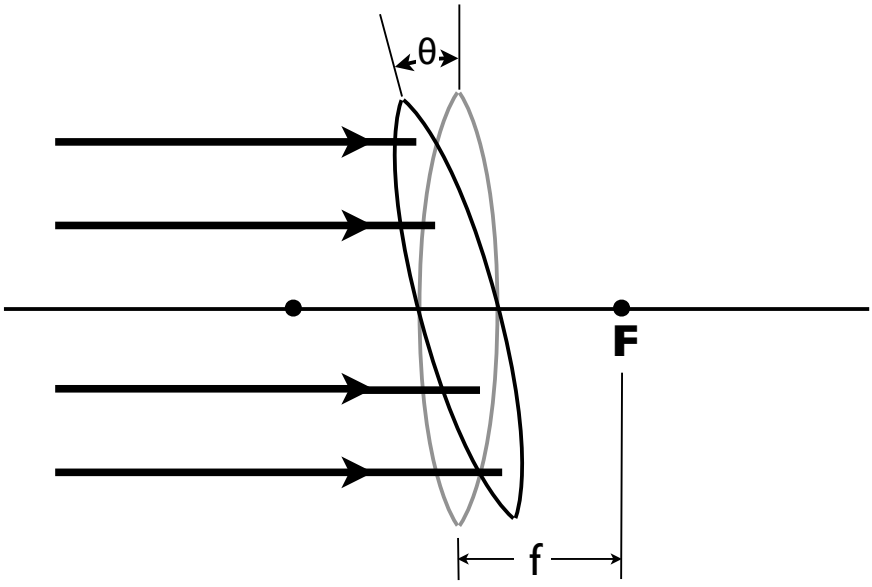
A) Yes

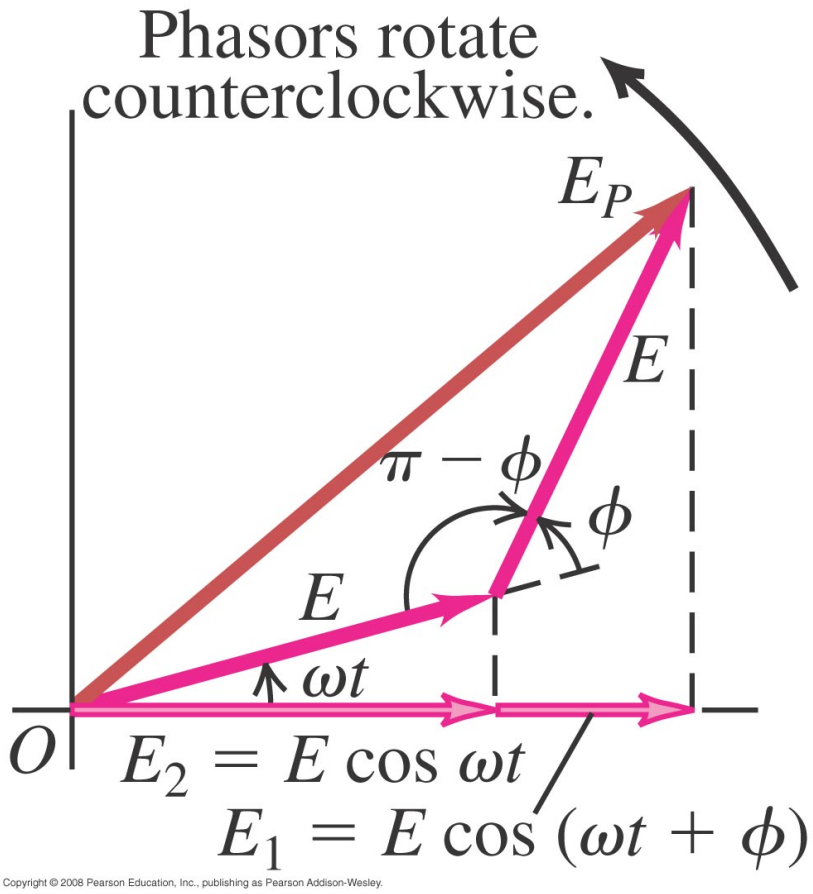
B) No

C) It can be either

Consider a converging lens with focal length f. Rays from a object at infinity converge at the focal point as shown.

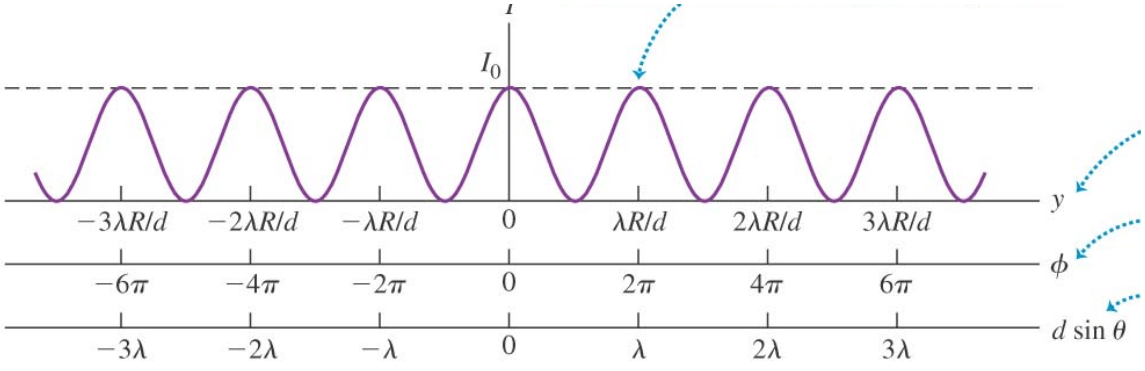
Where does the point of convergence move to if the lens is rotated a small angle θ? Specify the direction and the distance away from point "F." (Hint: Consider the principal ray through the center of the lens).

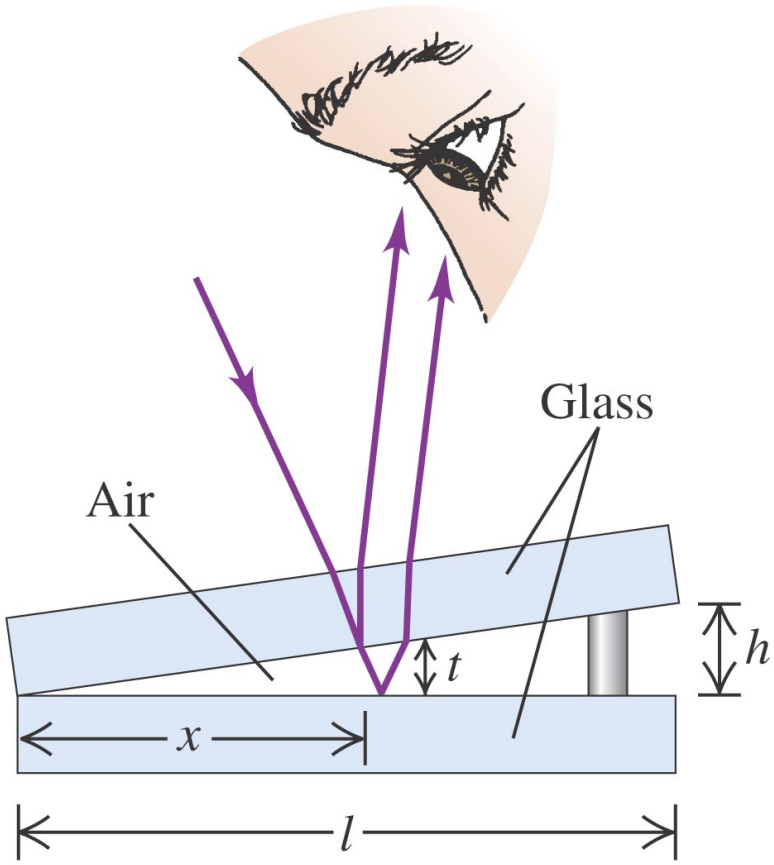




$$I = I_o \cos^2\left(\frac{\phi}{2}\right)$$

$$\phi = kd\sin(\theta)$$





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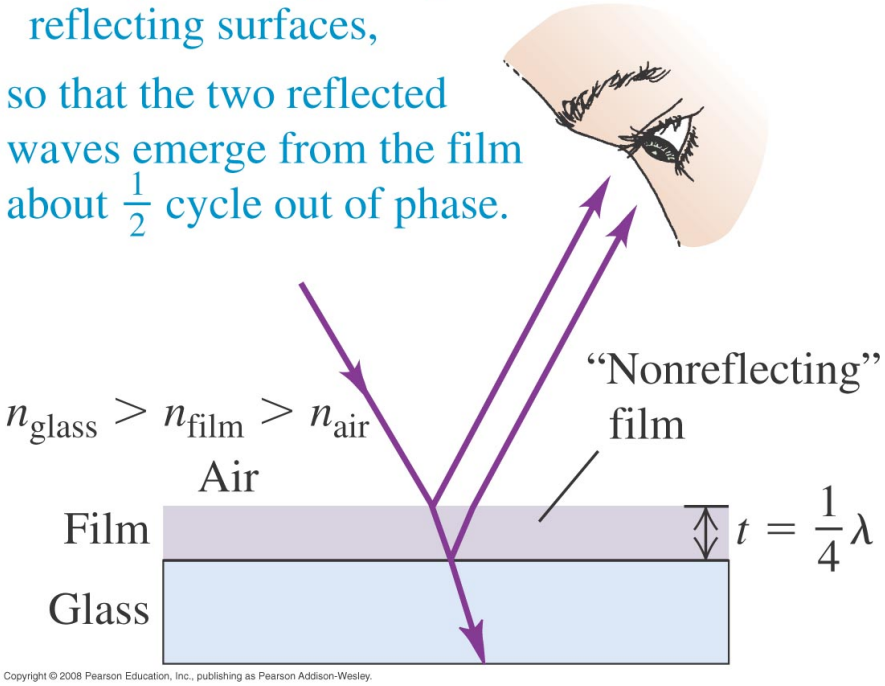
- the light undergoes a phase change at both reflecting surfaces,

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



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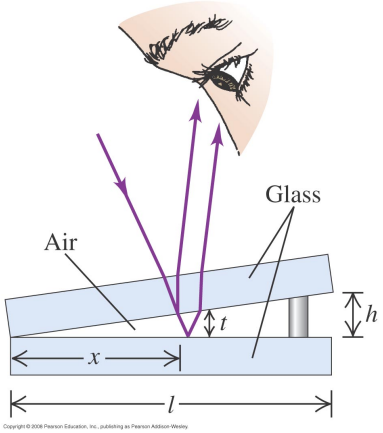

A. λ/2.

B. 3λ/4.

C. λ.

D. either A. or C.

E. any of A., B., or C.

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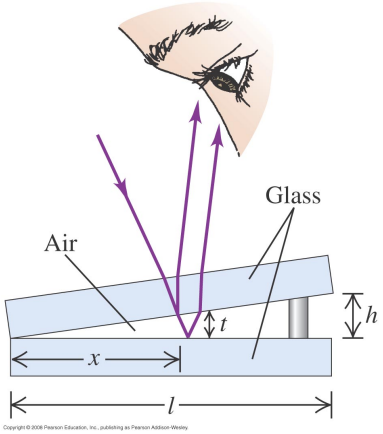

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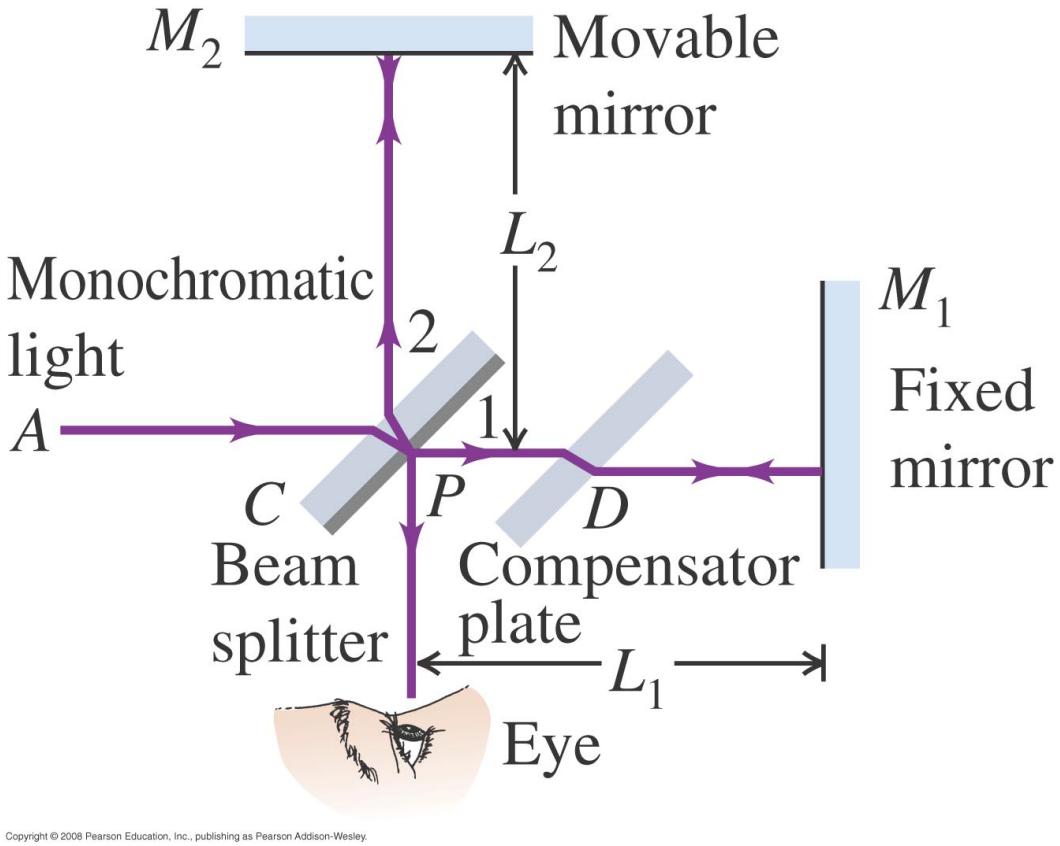
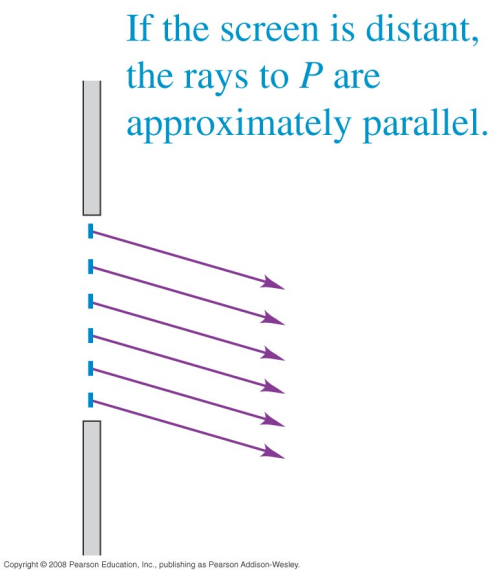
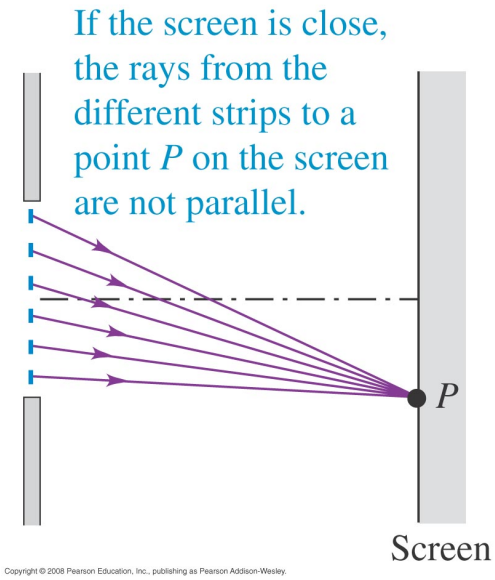


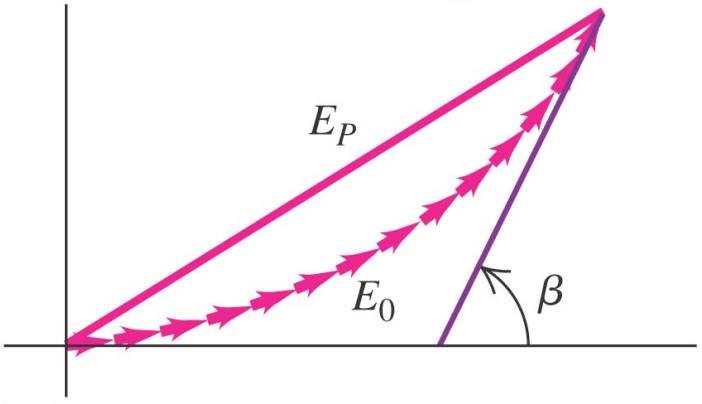
(c) Fraunhofer (far-field) diffraction

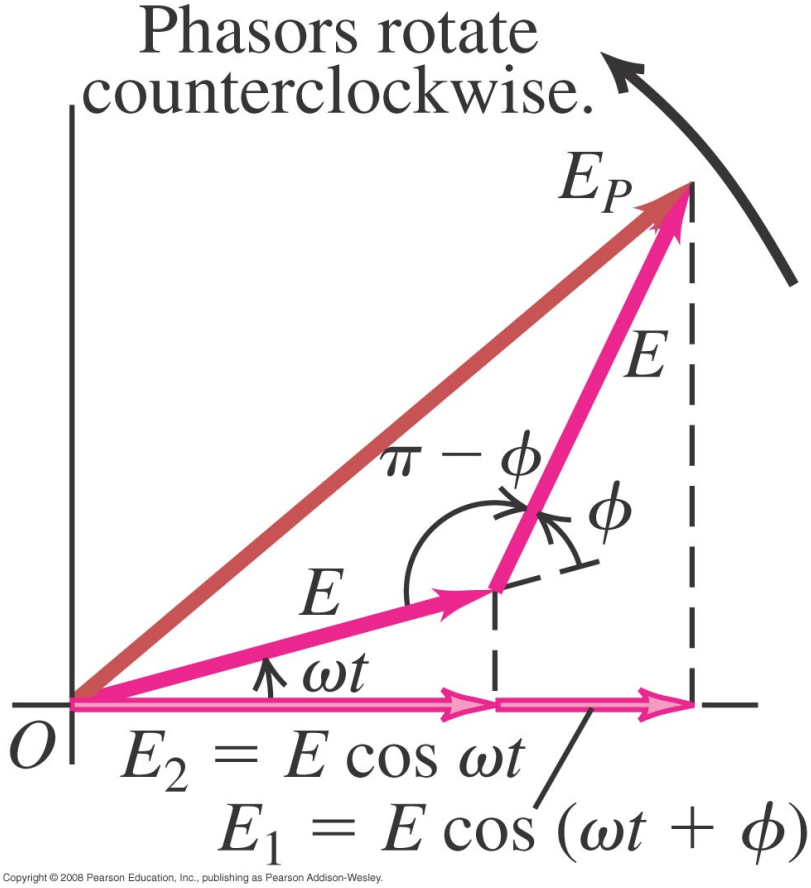


(b) Fresnel (near-field) diffraction

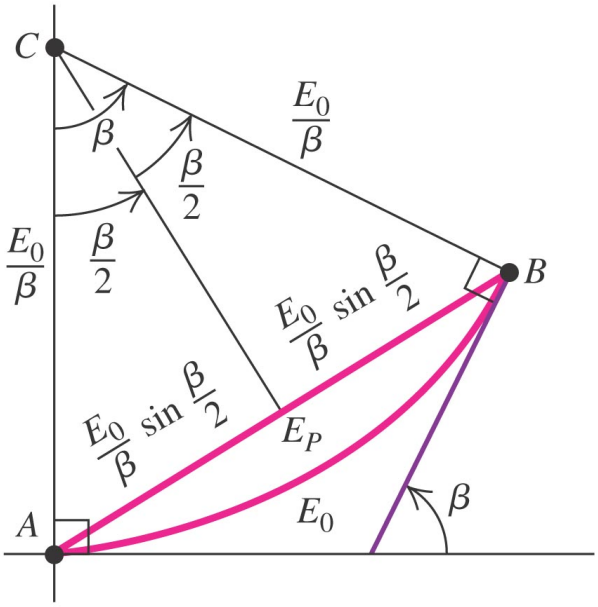


(c) Phasor diagram at a point slightly off the center of the pattern; β = total phase difference between the first and last phasors.



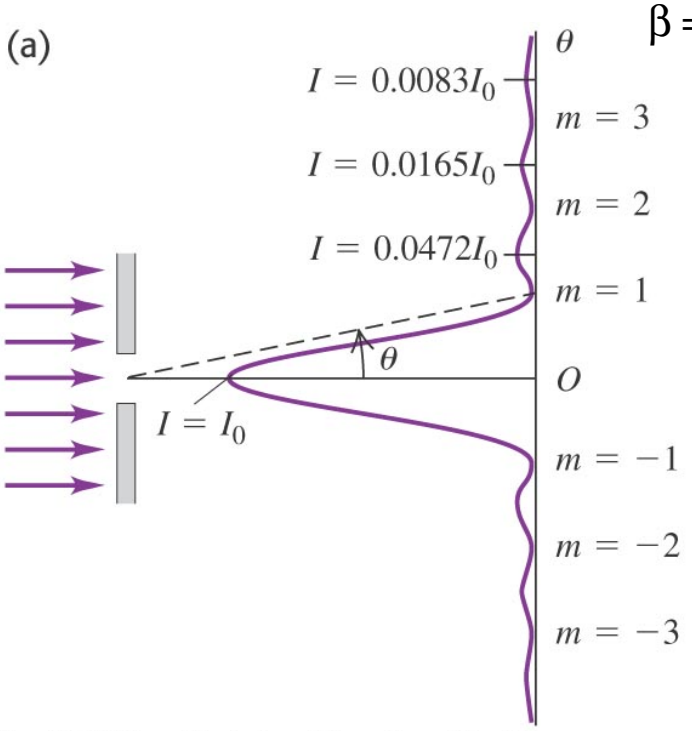


(d) As in (c), but in the limit that the slit is subdivided into infinitely many strips



$$\beta = k\,a\sin\theta = \frac{2\pi}{\lambda}a\sin\theta$$

$$E_P = E_O\,\frac{\sin\beta/2}{\beta/2}$$



$$\beta = k\,a\sin\theta = \frac{2\pi}{\lambda}a\sin\theta$$

$$I = I_O\left[\frac{\sin\beta/2}{\beta/2}\right]^2$$

Clicker Question

Will the separation between the first dark fringes get larger or smaller if the slit width is made larger?

a) Larger

b) Smaller

Clicker Question

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Clicker Question

In a single-slit diffraction experiment with waves of wavelength λ, there will be *no* intensity minima (that is, no dark fringes) if the slit width is small enough.

What is the *maximum* slit width *a* for which this occurs?

A. $a = \lambda/2$

B. $a = \lambda$

C. $a = 2\lambda$

D. The answer depends on the distance from the slit to the screen on which the diffraction pattern is viewed.

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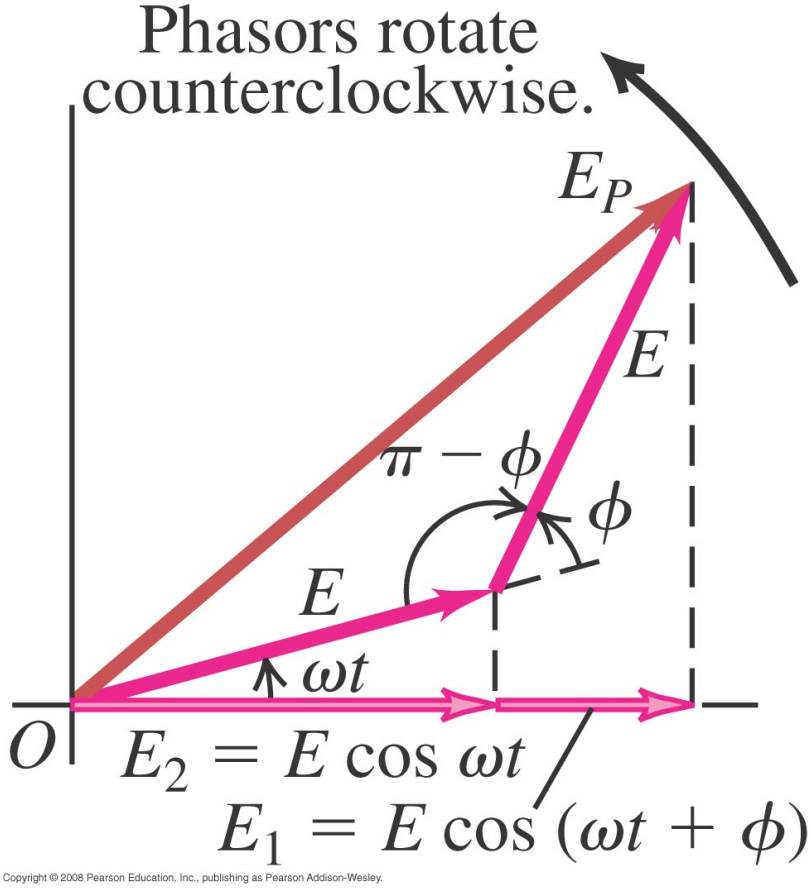
Lecture 15



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

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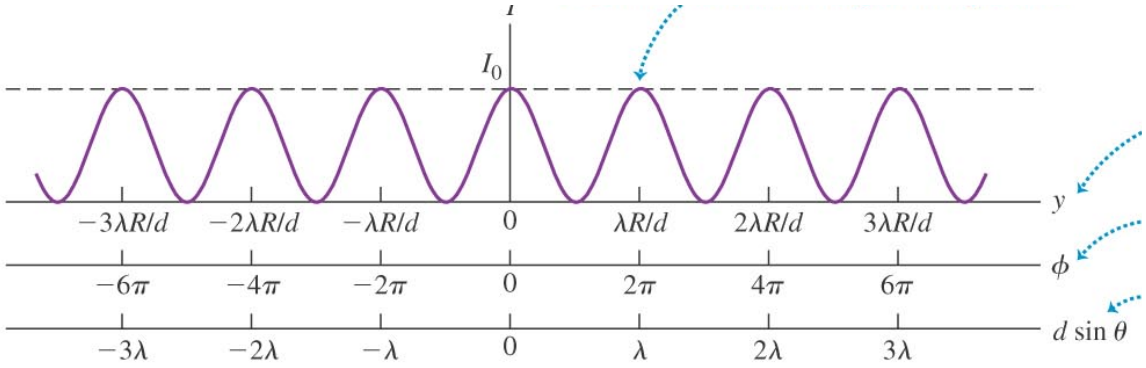
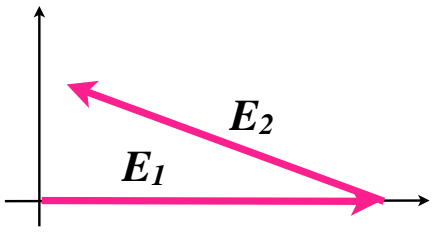


Clicker Question

At a particular point in space, the electric field from two sources add according to the phasor diagram at right. Which of the following statements is true for the resulting intensity?



A) The resulting intensity is twice that of a single source

B) The resulting intensity is greater than if only one source was present

C) The resulting intensity is zero

D) The resulting intensity is smaller than if only one source was present

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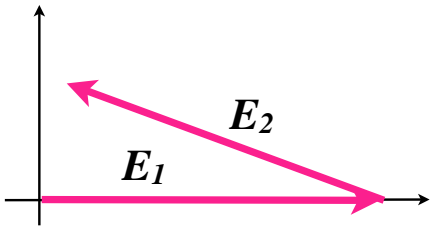

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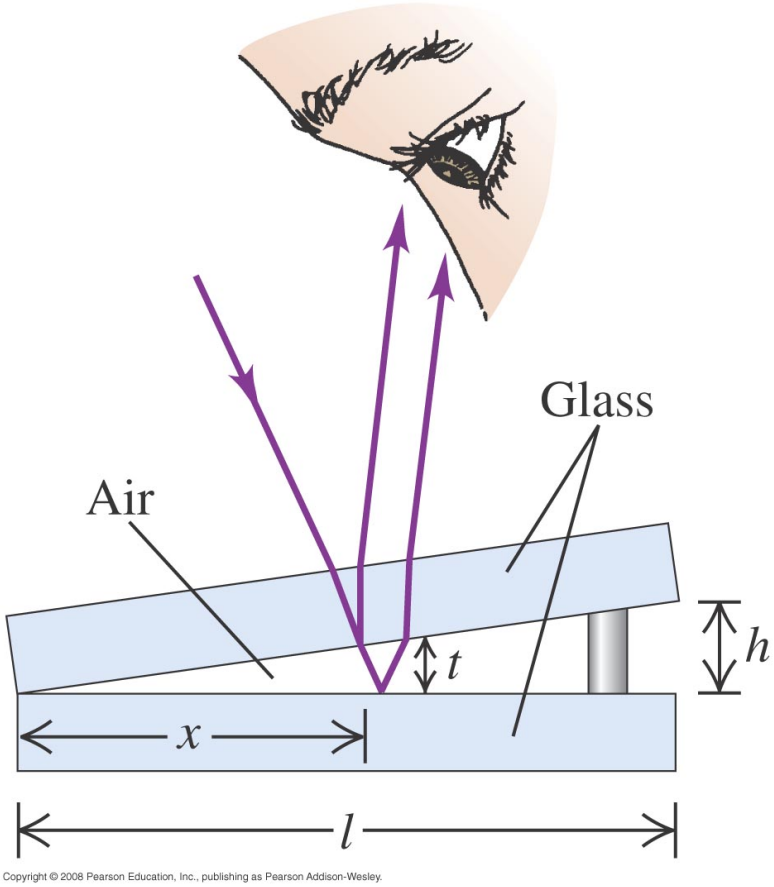

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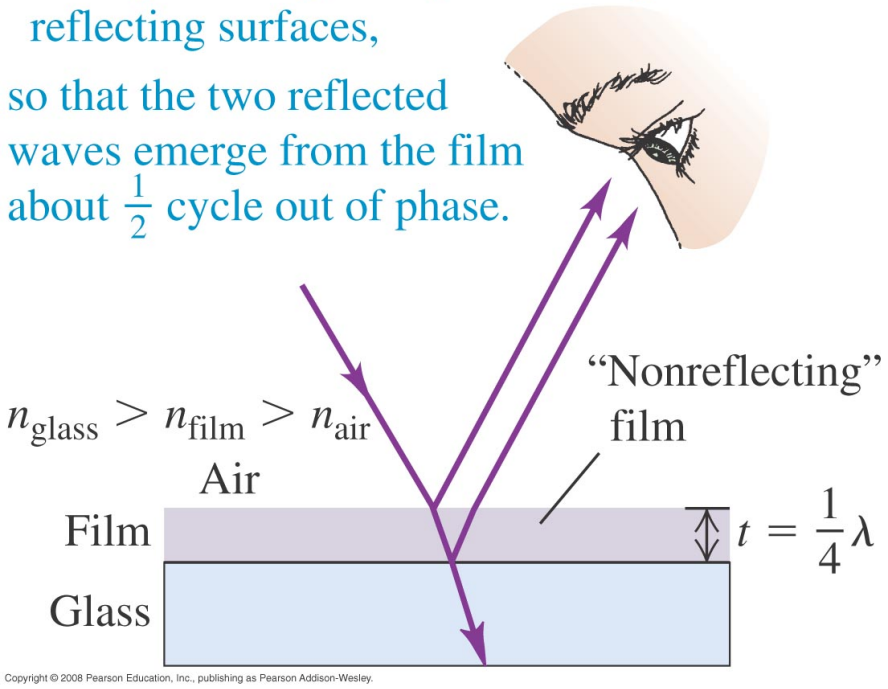

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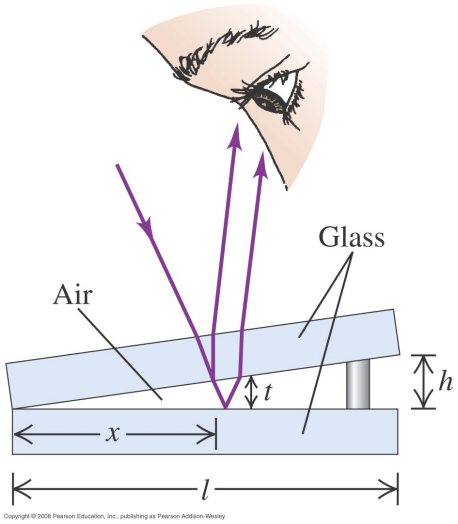

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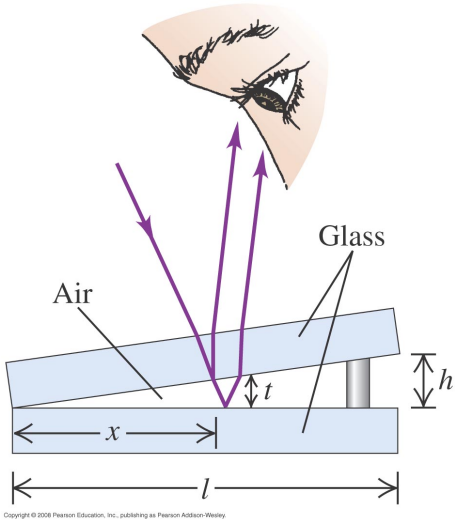

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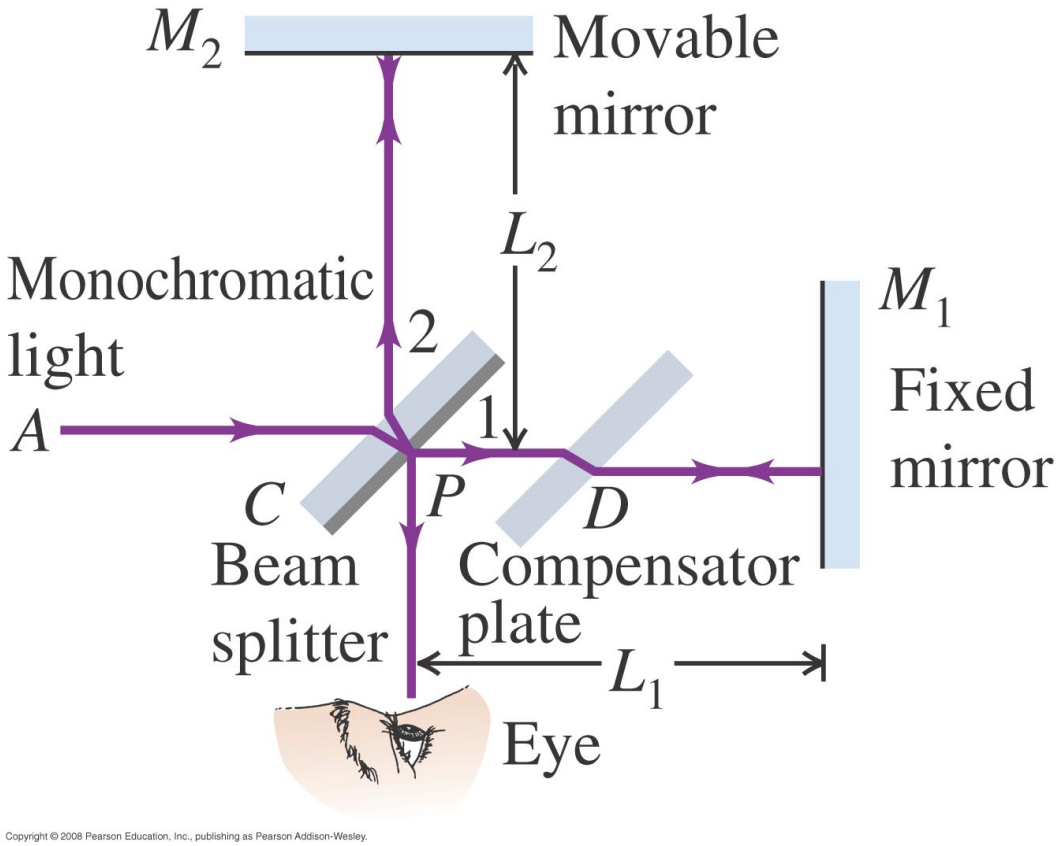
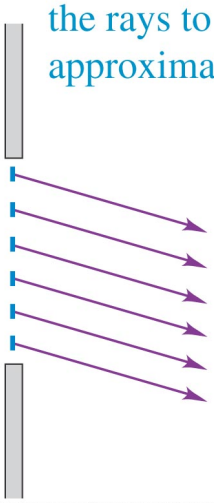


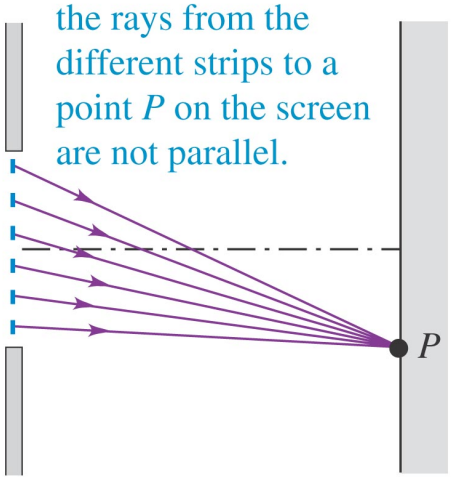
(c) Fraunhofer (far-field) diffraction

If the screen is distant, the rays to P are approximately parallel.



(b) Fresnel (near-field) diffraction

If the screen is close, the rays from the different strips to a point P on the screen are not parallel.



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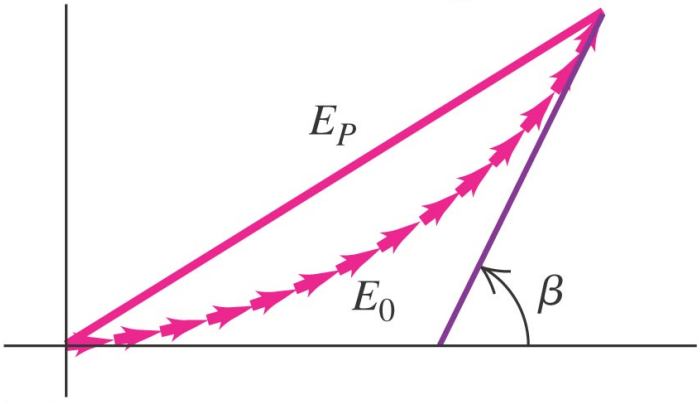

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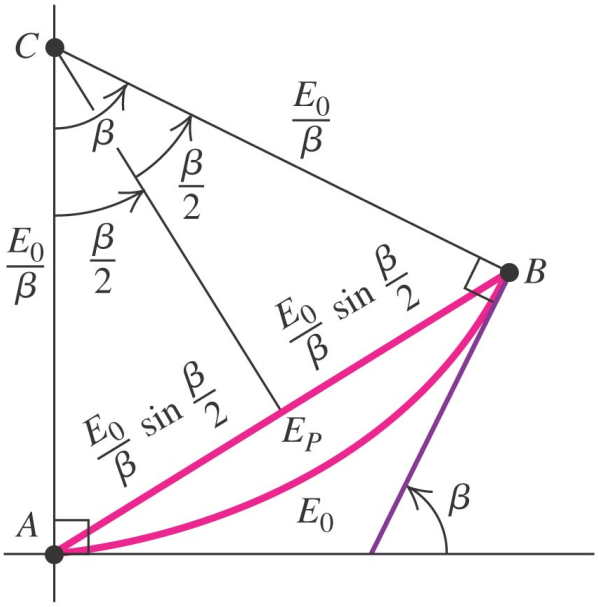

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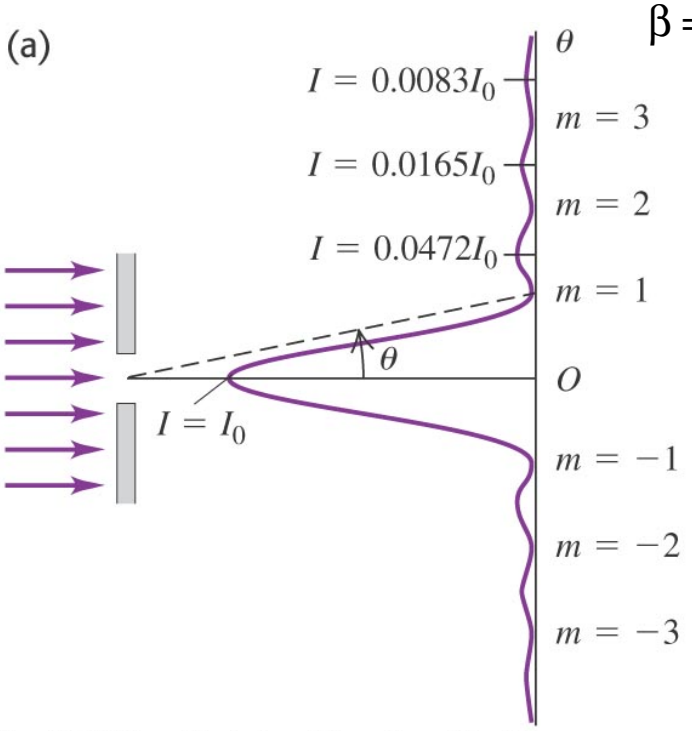

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$$I = I_O\left[\frac{\sin\beta/2}{\beta/2}\right]^2$$

Clicker Question

Light of wavelength λ passes through a single slit of width a. The diffraction pattern is observed on a screen that is very far from from the slit.

Which of the following will give the greatest increase in the angular width of the central diffraction maximum?

A) Double the slit width a and double the wavelength λ.

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C) Halve the slit width a and double the wavelength λ.

D) Halve the slit width a and halve the wavelength λ.

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What is the *maximum* slit width a for which this occurs?

A. $a = \lambda/2$

B. $a = \lambda$

C. $a = 2\lambda$

D. The answer depends on the distance from the slit to the screen on which the diffraction pattern is viewed.

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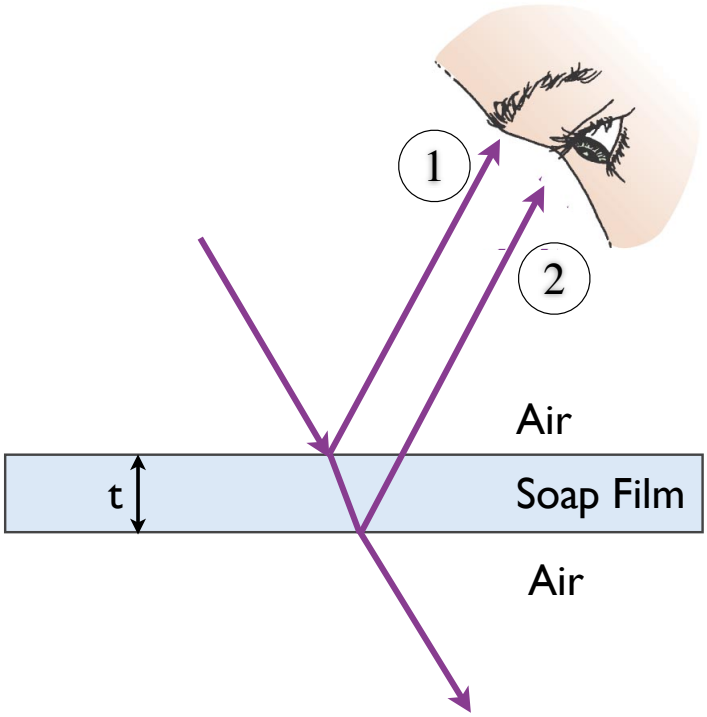
Lecture 16



Clicker Question

A person observes interference from monochromatic light reflected off of a soap film suspended in air

What is the phase shift experienced by Ray 1 upon reflection?

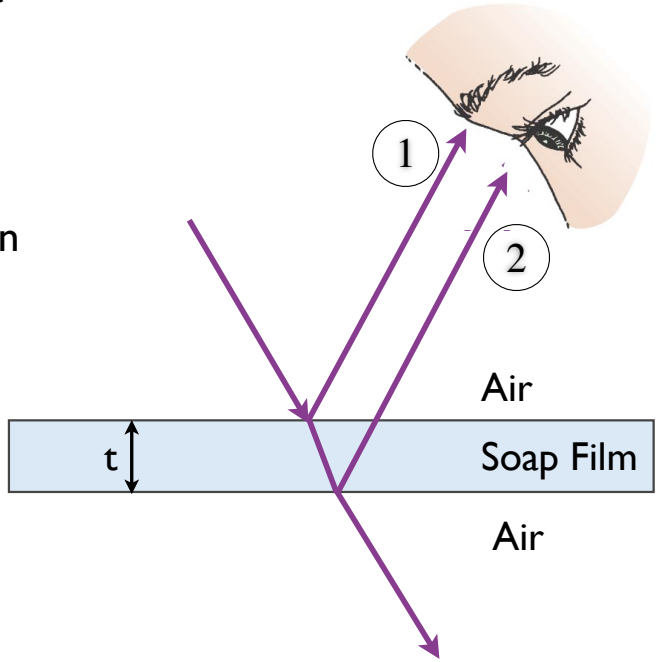
A) 0

B) π/2

C) π

D) λ

E) 2λ



Clicker Question

A person observes interference from monochromatic light reflected off of a soap film suspended in air

Which describes the phase shift experienced by Ray 2 upon reflection?

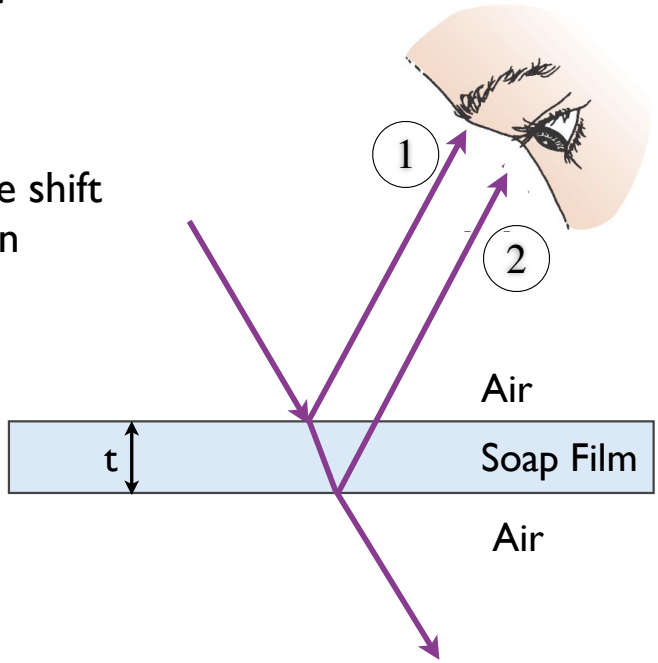
A) 0

B) 2t

C) π

D) k2t

E) k2t+π



Clicker Question

A person observes interference from monochromatic light reflected off of a soap film suspended in air

Which describes the difference in phase shift between Ray 2 and Ray 1 upon reflection?

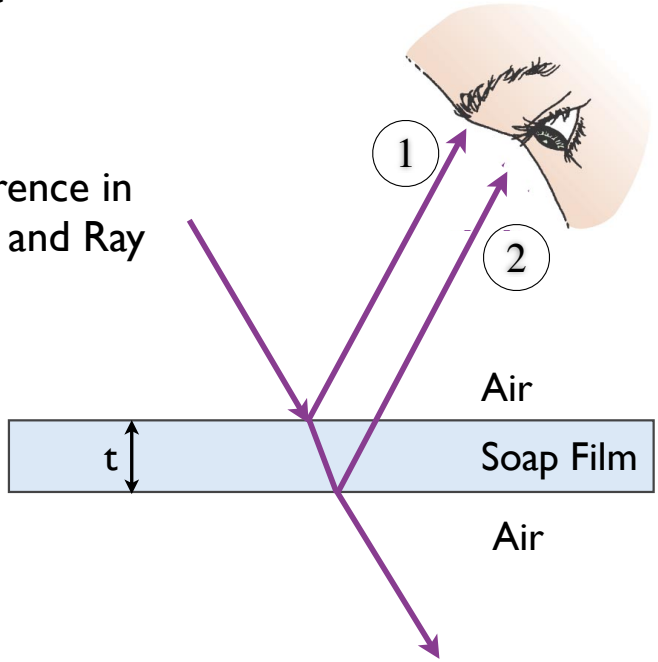
A) 0

B) $2t+\pi$

C) π

D) $k2t+\pi$

E) $k2t-\pi$



Clicker Question

A person observes interference from monochromatic light reflected off of a soap film suspended in air

Which describes the condition for constructive interference between Ray 2 and Ray 1 upon reflection?

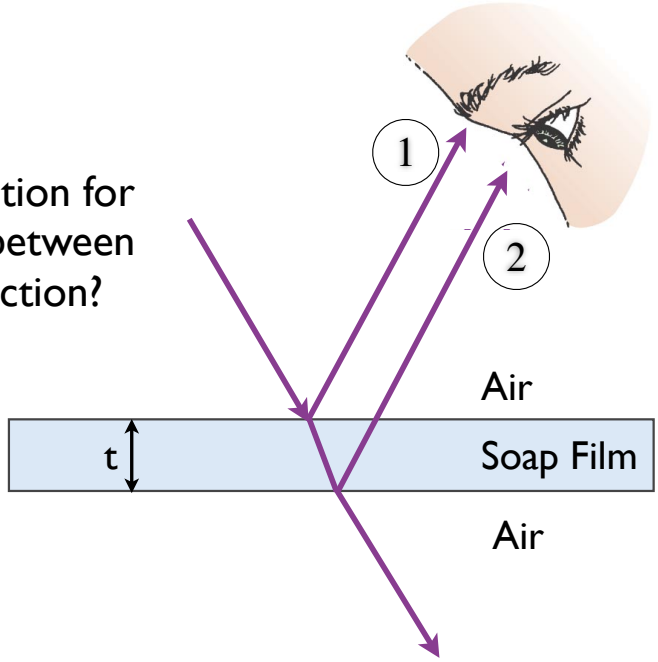
A) $k2t-\pi = 2m\pi$

B) $k2t = 2m\pi$

C) $k2t = m\lambda$

D) $k2t-\pi = (2m+1)\lambda$

E) $k2t-\pi = m\lambda$



Clicker Question

Two identical slides in air are illuminated with monochromatic light. The slides are exactly parallel, and the top slide is moving slowly upward. What do you see in top view?

A) All black

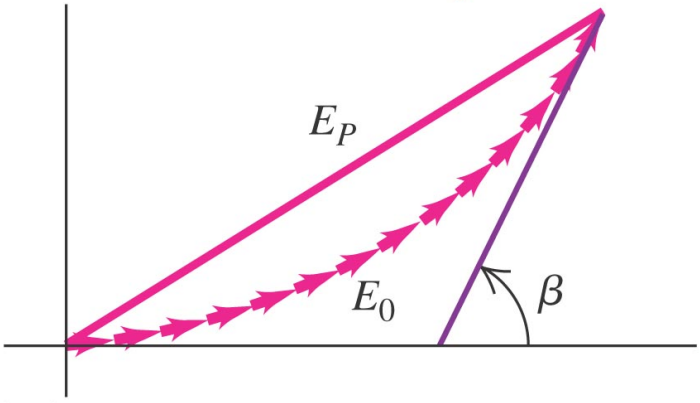
B) All bright

C) Fringes that move apart slowly

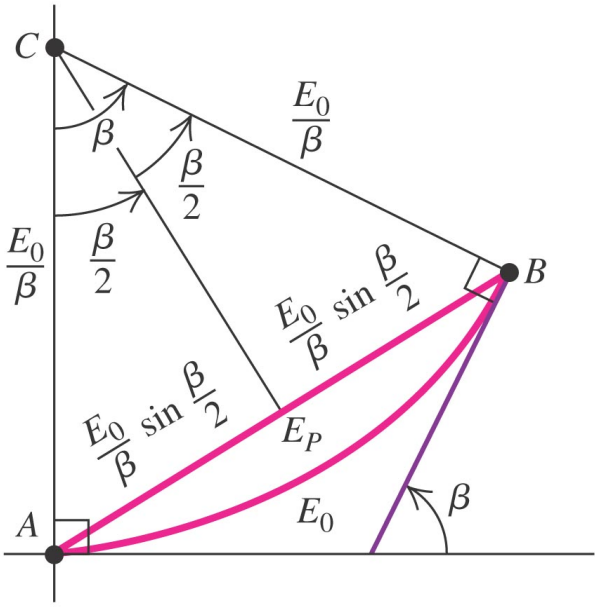
D) Sequentially all black, then all bright repeating in time

E) None of these

(c) Phasor diagram at a point slightly off the center of the pattern; β = total phase difference between the first and last phasors.



(d) As in (c), but in the limit that the slit is subdivided into infinitely many strips



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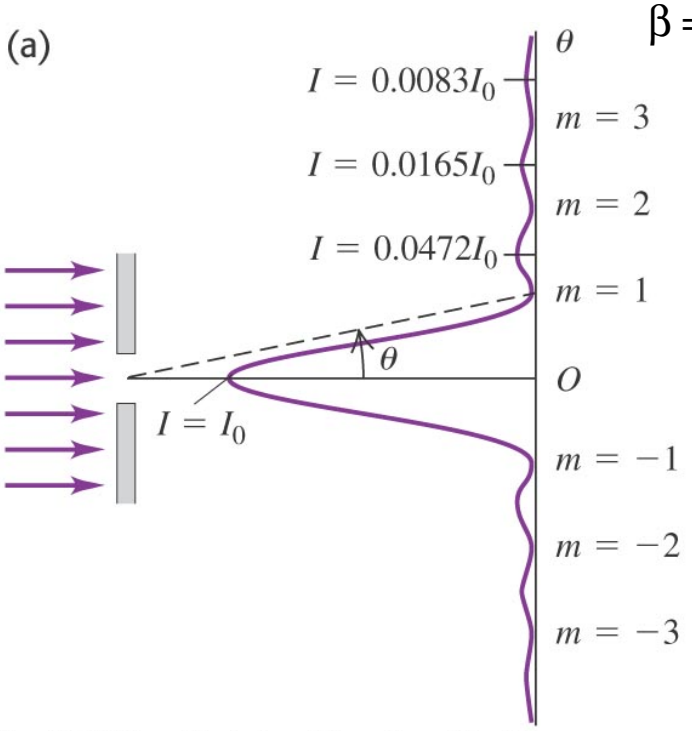

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Clicker Question

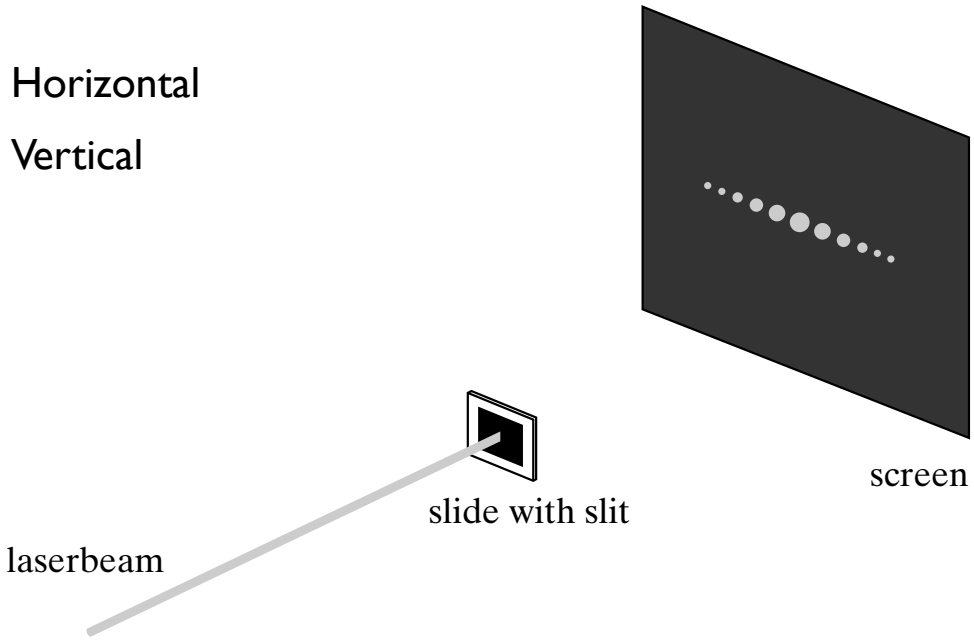
Diffraction occurs when light passes a:

A) pinhole
B) narrow slit
C) wide
D) sharp edge
E) all of the above

Clicker Question

The pattern on the screen is due to a narrow slit that is

A) Horizontal
B) Vertical



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Clicker Question

Blue light of wavelength λ passes through a single slit of width *a* and forms a diffraction pattern on a screen. If the blue light is replaced by red light of wavelength 2λ, the original diffraction pattern is reproduced if the slit width is changed to

A) *a*/4

B) *a*/2

C) No change is necessary.

D) 2*a*

E) 4*a*

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Figure 36.15a

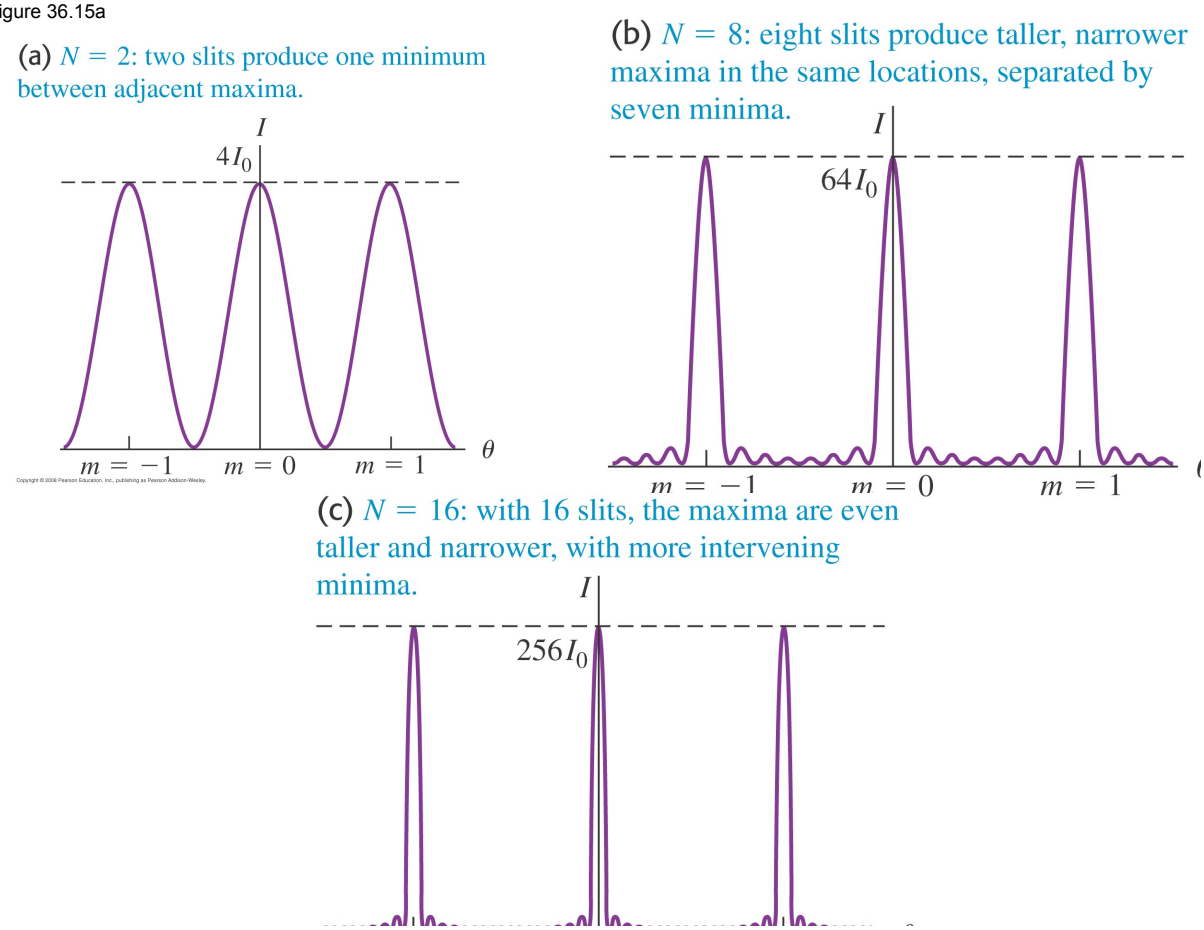


Figure 36.16

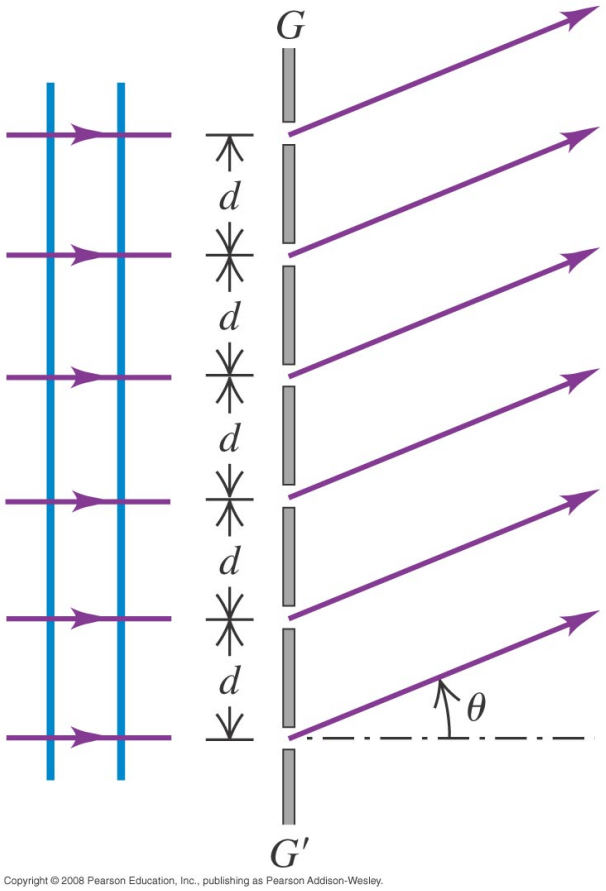
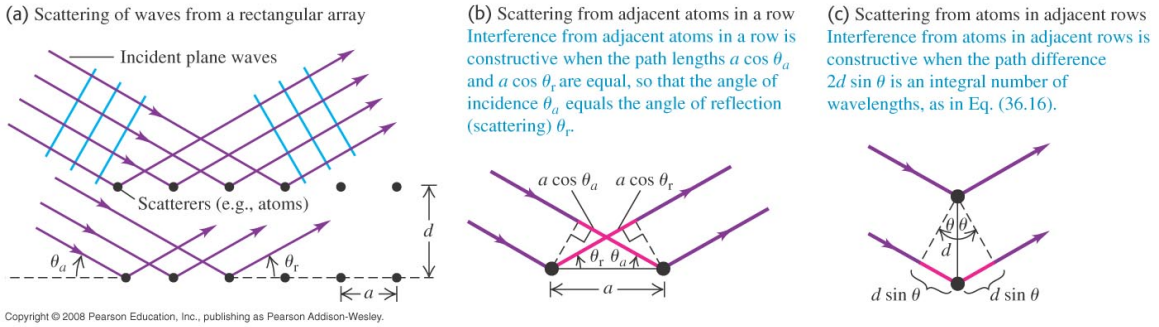
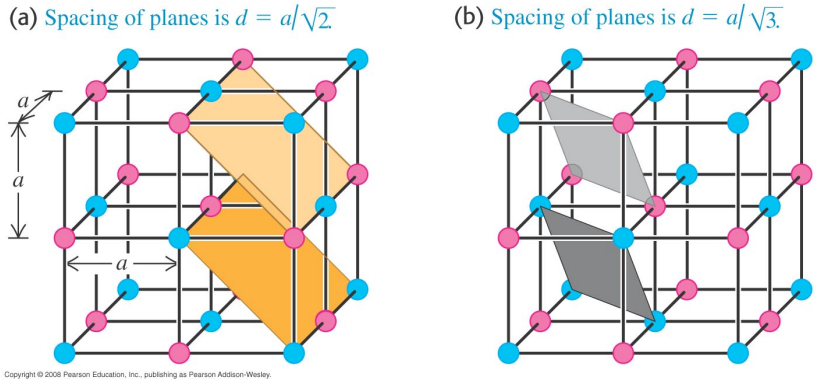


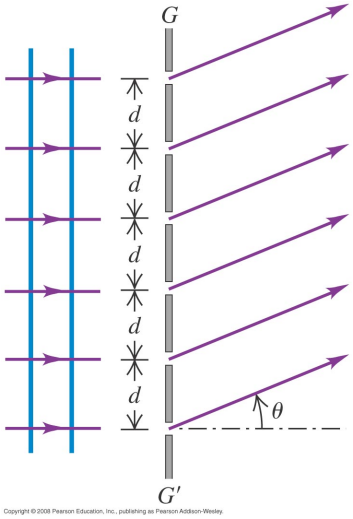
Figure 36.23





Clicker Question

Coherent light passing through six (6) slits separated by a distance d produces a pattern of dark and bright areas on a distant screen. There will be a dark area on the screen at a position where the path difference to the screen from adjacent slits is



A. $\lambda/2$.

B. $\lambda/3$.

C. $\lambda/6$.

D. any of these.

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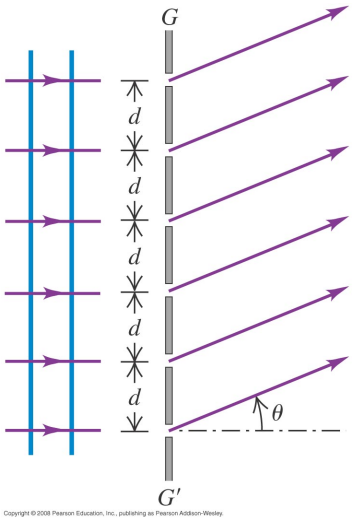

A. λ/2.

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C. λ/6.

D. any of these.

Clicker Question

What is more important in a telescope or microscope:

a) Magnification

b) Resolution

Clicker Question

What is more important in a telescope or microscope:

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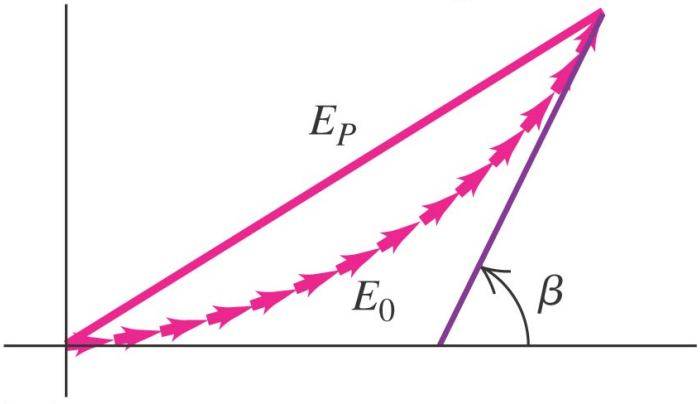
Lecture 17

(c) Phasor diagram at a point slightly off the center of the pattern; β = total phase difference between the first and last phasors.



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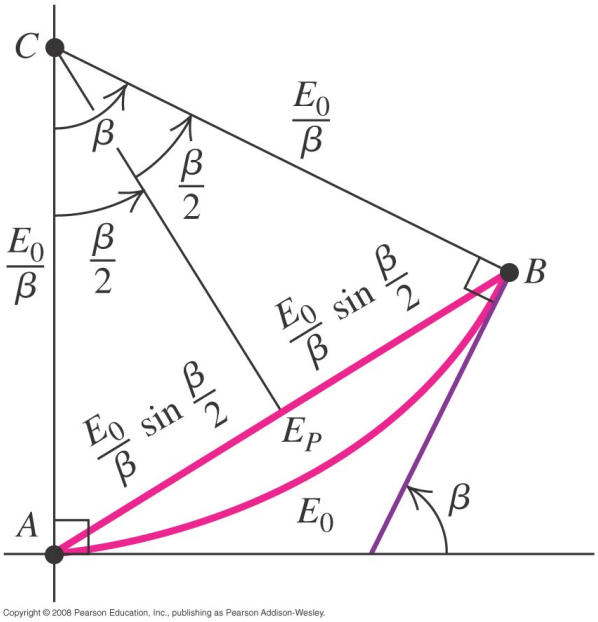

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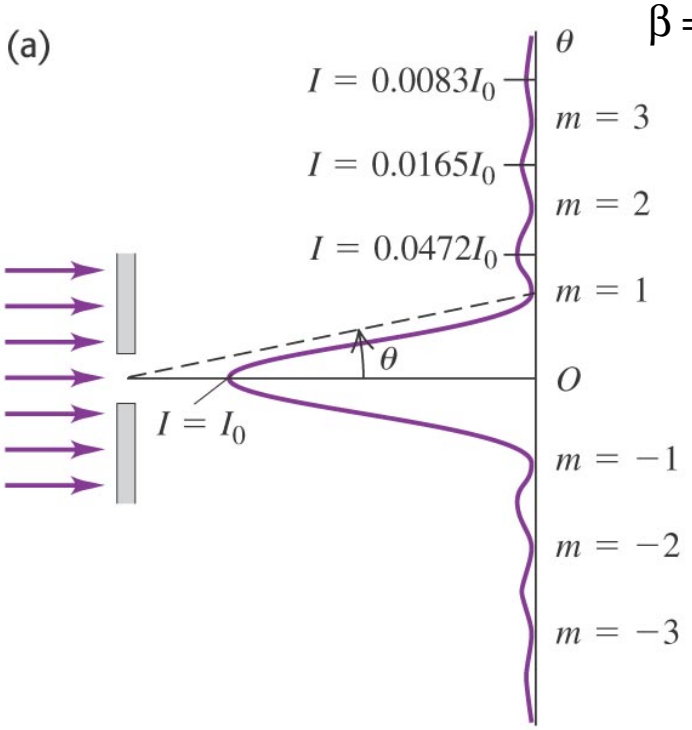

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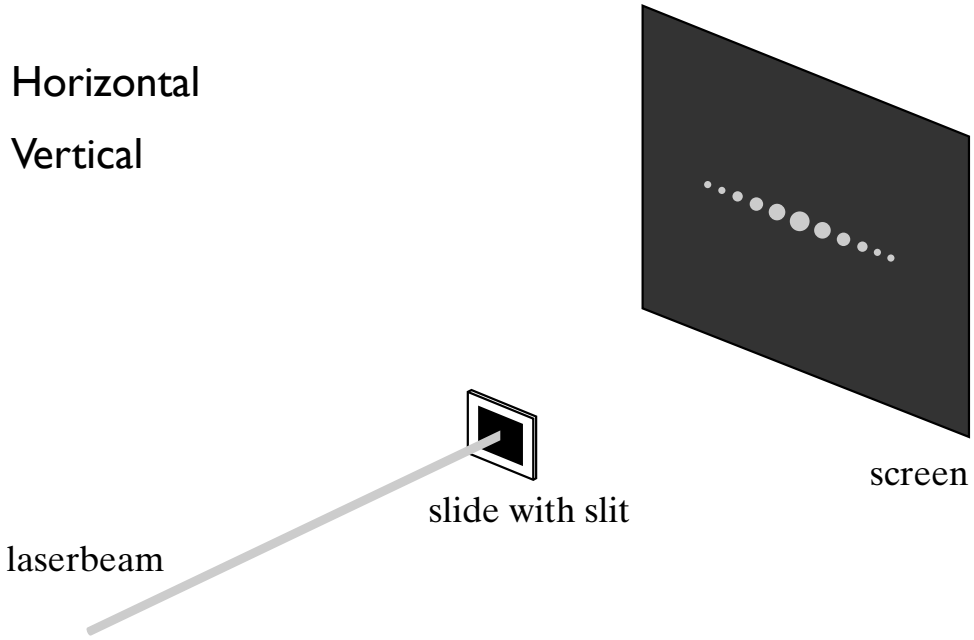

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Figure 36.16

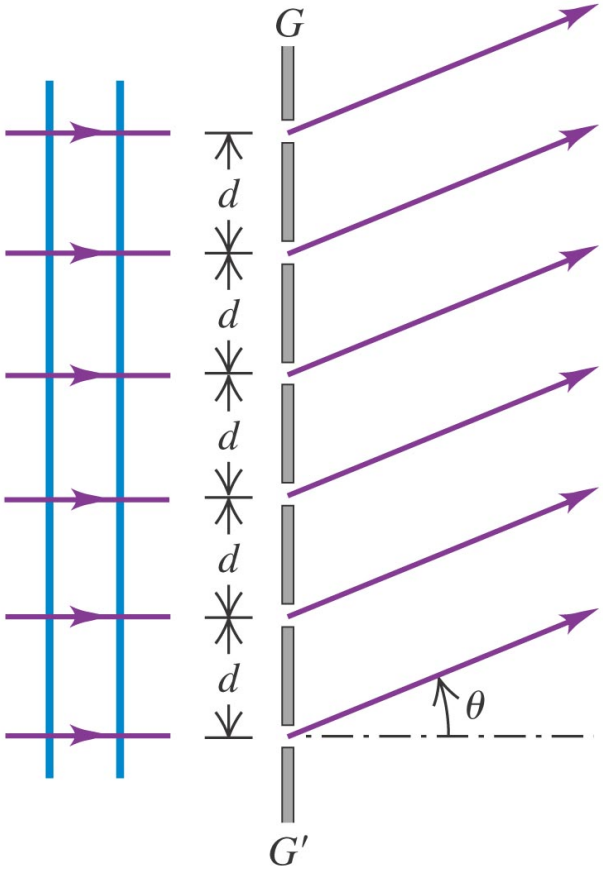
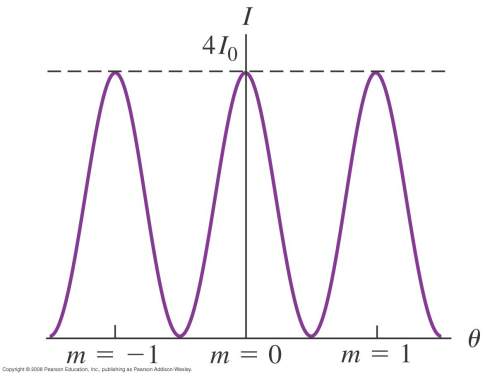
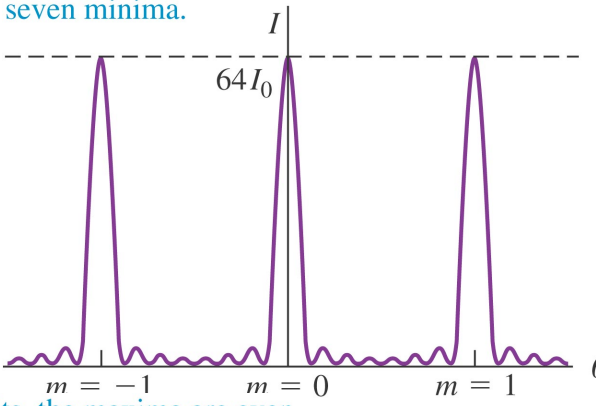


Figure 36.15a

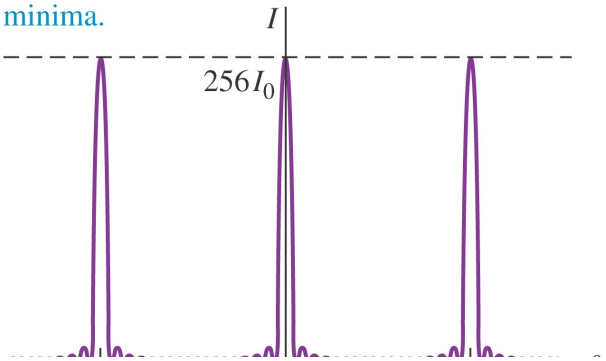
(a) $N = 2$: two slits produce one minimum between adjacent maxima.



(b) $N = 8$: eight slits produce taller, narrower maxima in the same locations, separated by seven minima.



(c) $N = 16$: with 16 slits, the maxima are even taller and narrower, with more intervening minima.



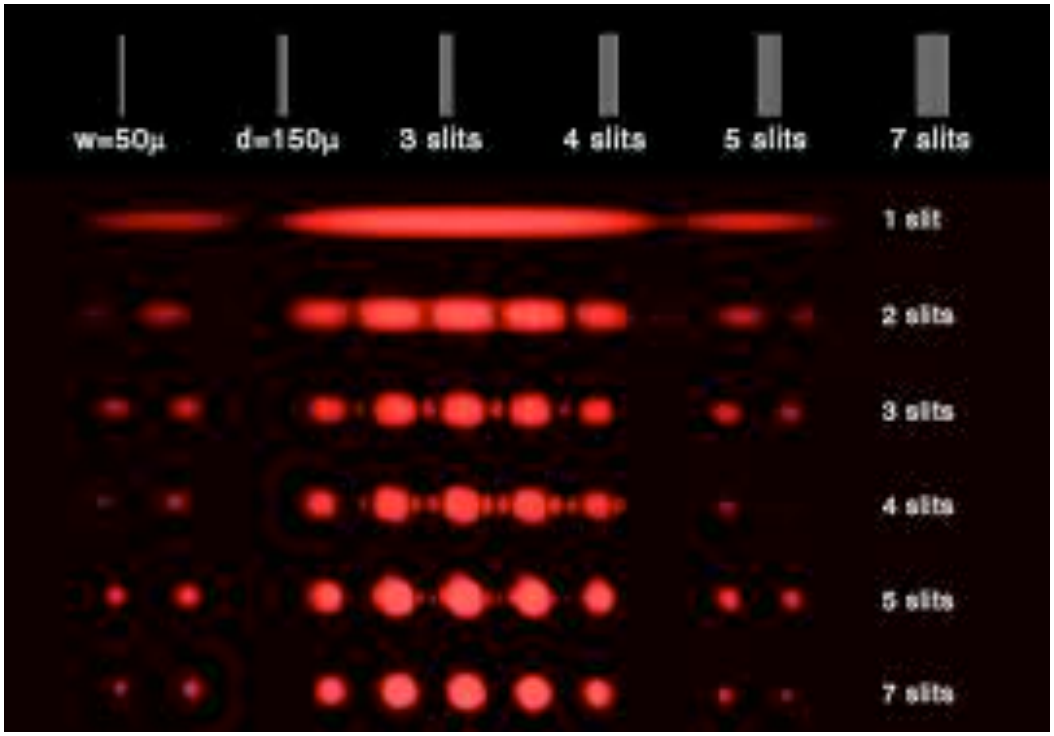
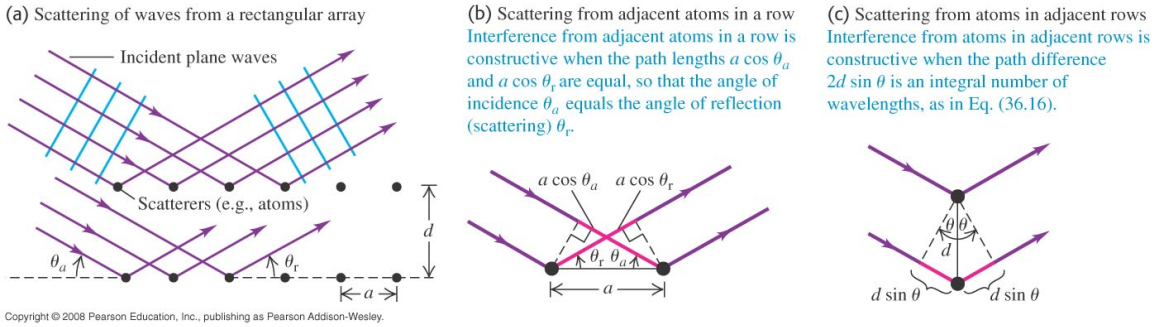
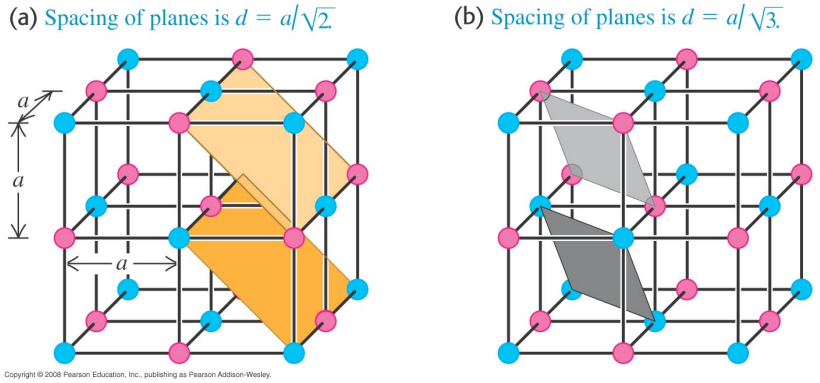


Figure 36.23





Clicker Question

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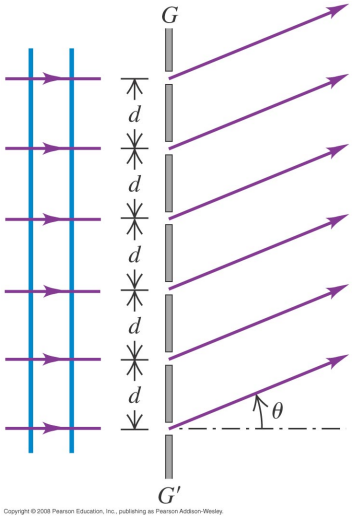

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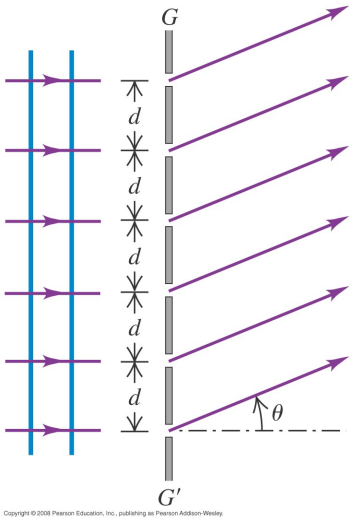

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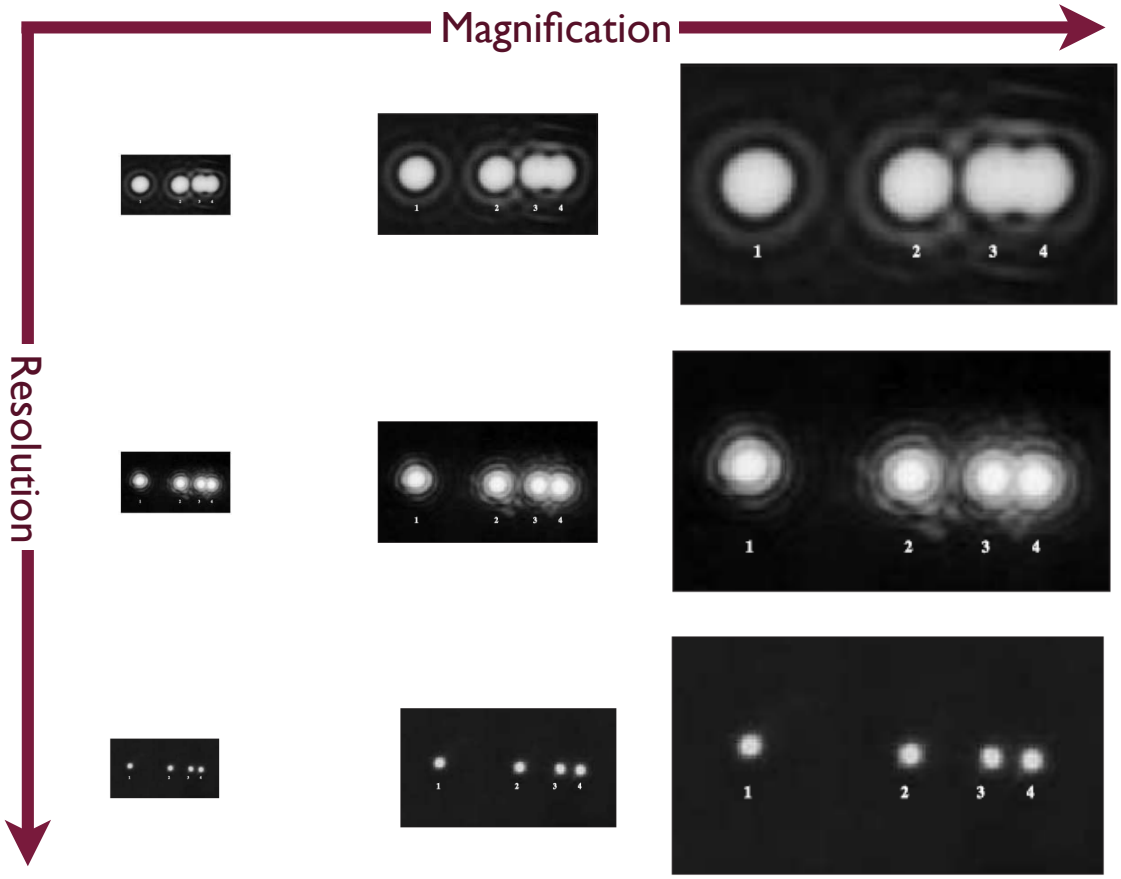
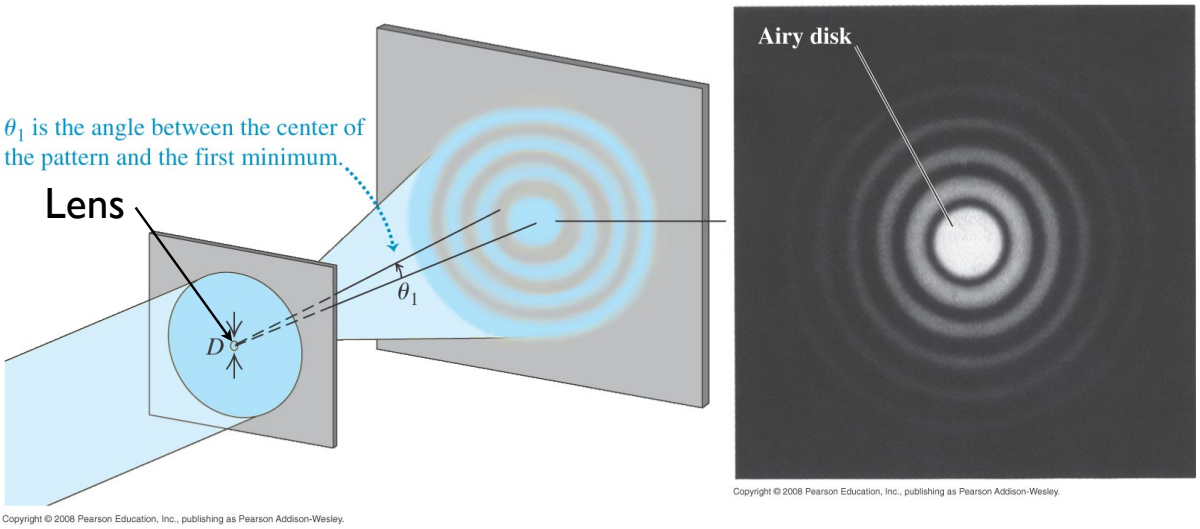


Lens- Circular Aperture



$$\sin(\theta_1) = 1.22\frac{\lambda}{D}$$

Clicker Question

What is more important in a telescope or microscope:

A) Magnification

B) Resolution

Clicker Question

What is more important in a telescope or microscope:

A) Magnification

B) Resolution

Clicker Question

What is more important in a telescope or microscope:

A) Magnification

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Provided the pixel separation in the detector can resolve the separation

Clicker Question

You use a telescope lens to form an image of two closely-spaced, distant stars. Which of the following will increase the resolving power?

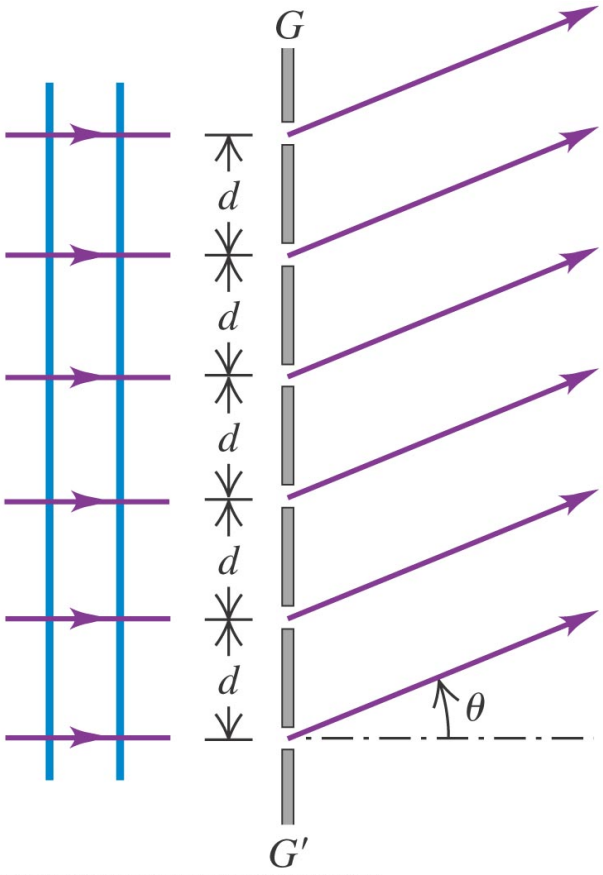
A) Use a filter so that only the blue light from the stars enters the lens.

B) Use a filter so that only the red light from the stars enters the lens.

C) Use a lens of smaller diameter.

D) more than one of the above

Figure 36.16



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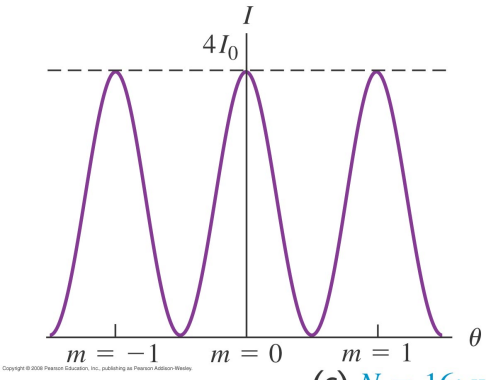

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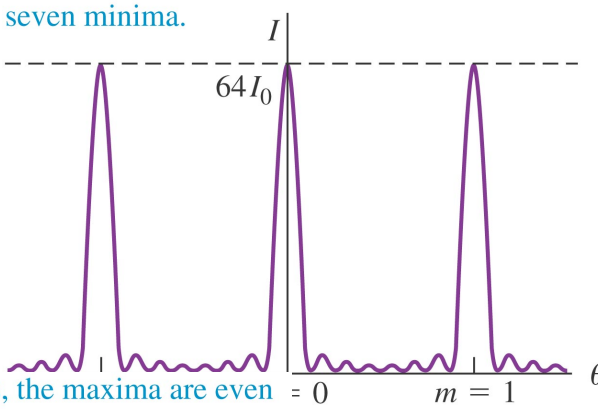
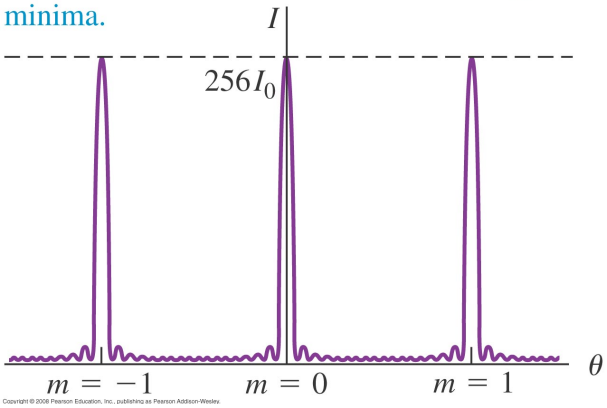


(c) $N = 16$: with 16 slits, the maxima are even taller and narrower, with more intervening minima.



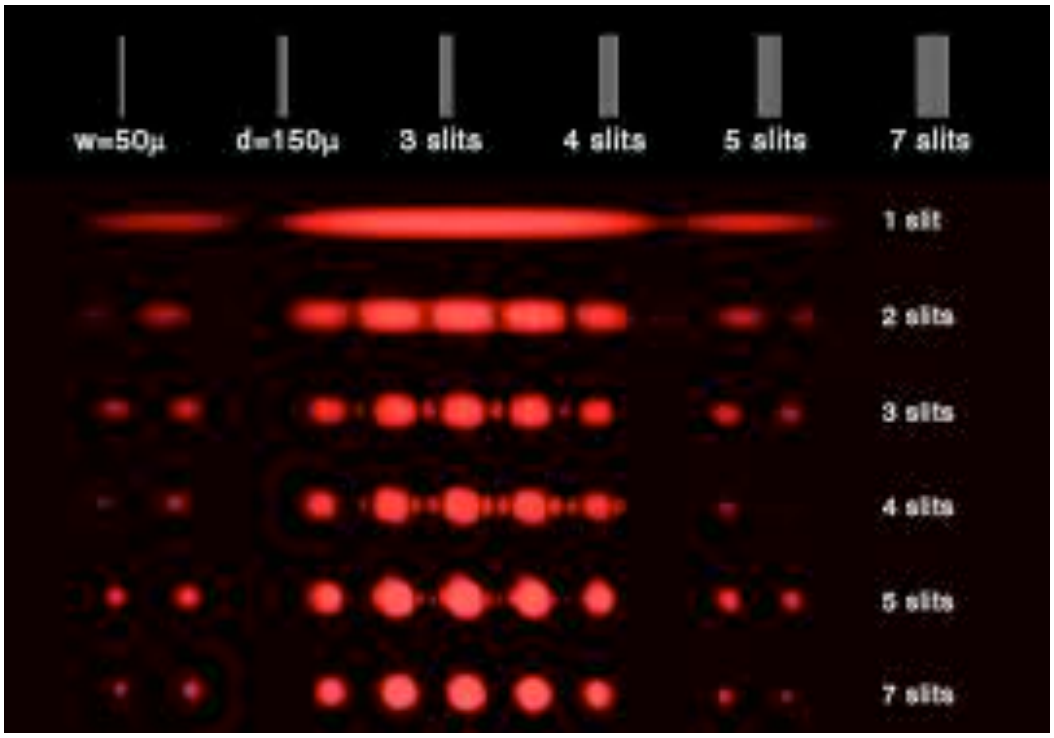
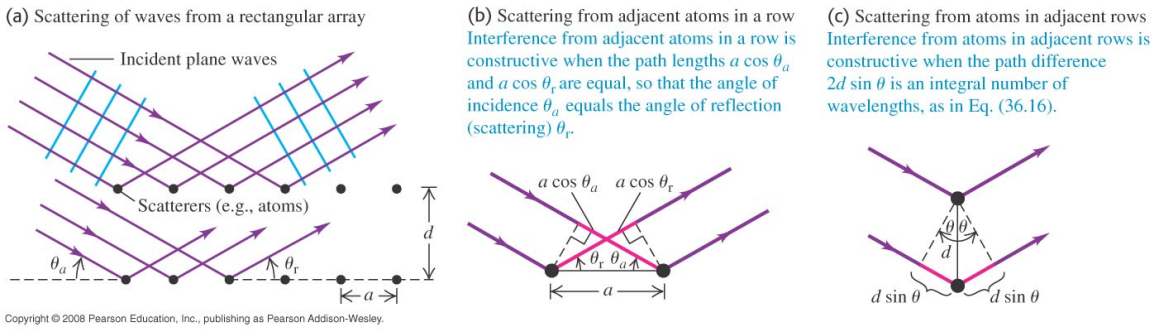
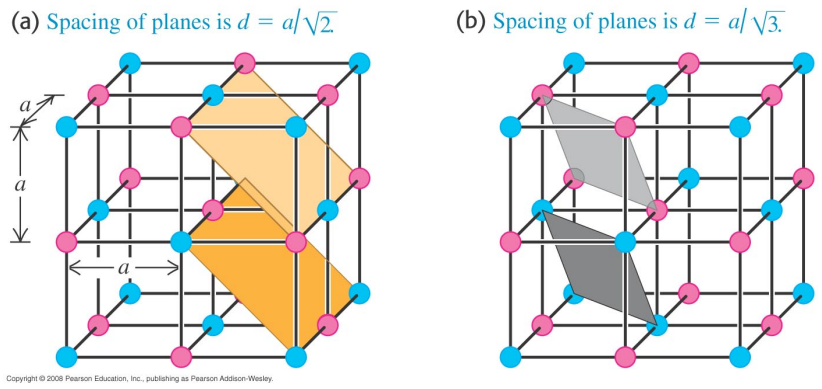


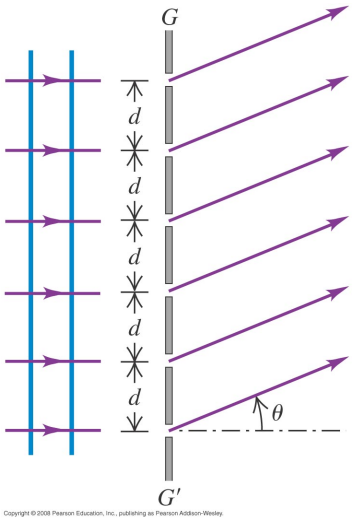
Figure 36.23





Clicker Question

Coherent light passing through six (6) slits separated by a distance *d* produces a pattern of dark and bright areas on a distant screen. There will be a dark area on the screen at a position where the path difference to the screen from adjacent slits is



A. λ/2. B. λ/3.

C. λ/6. D. any of these.

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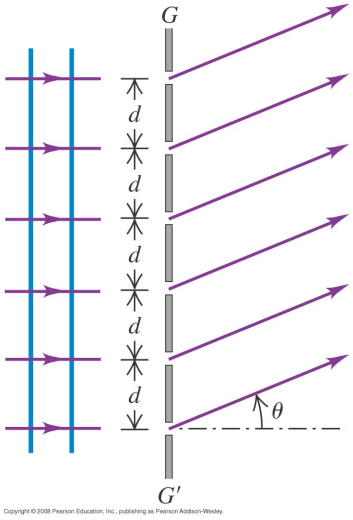
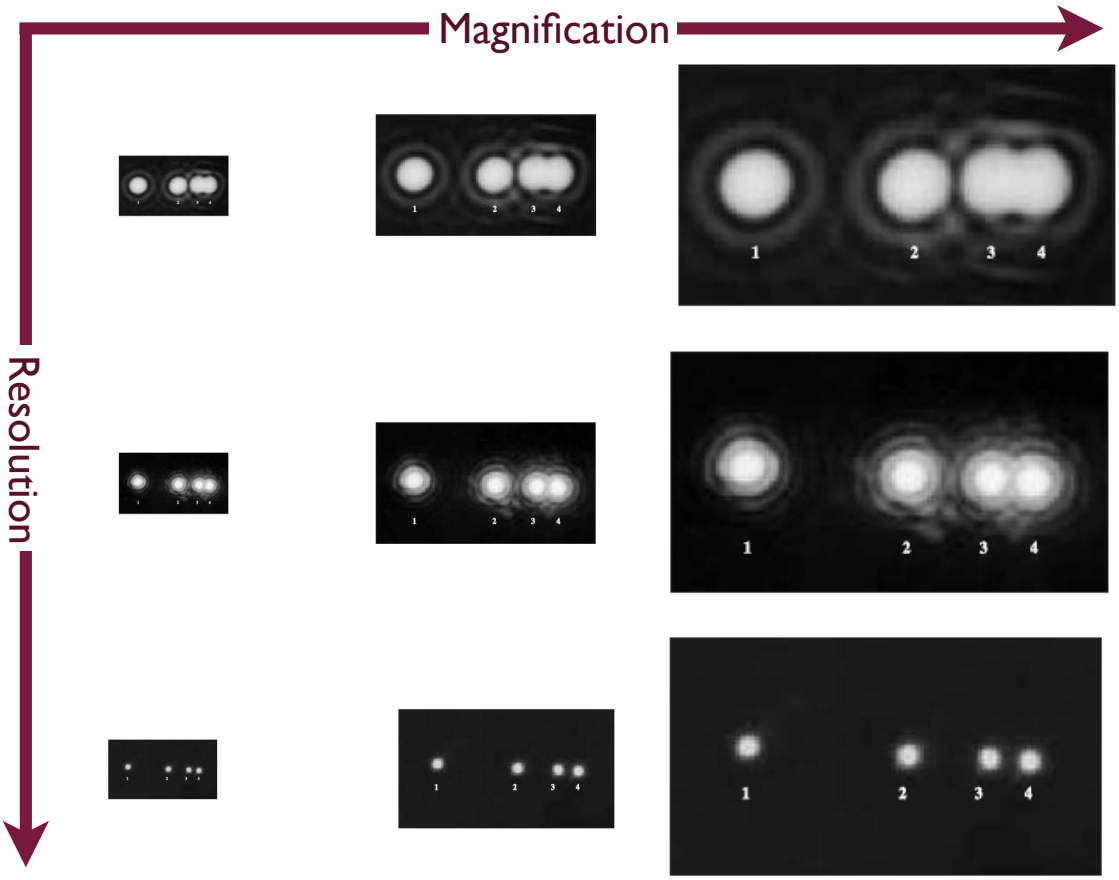
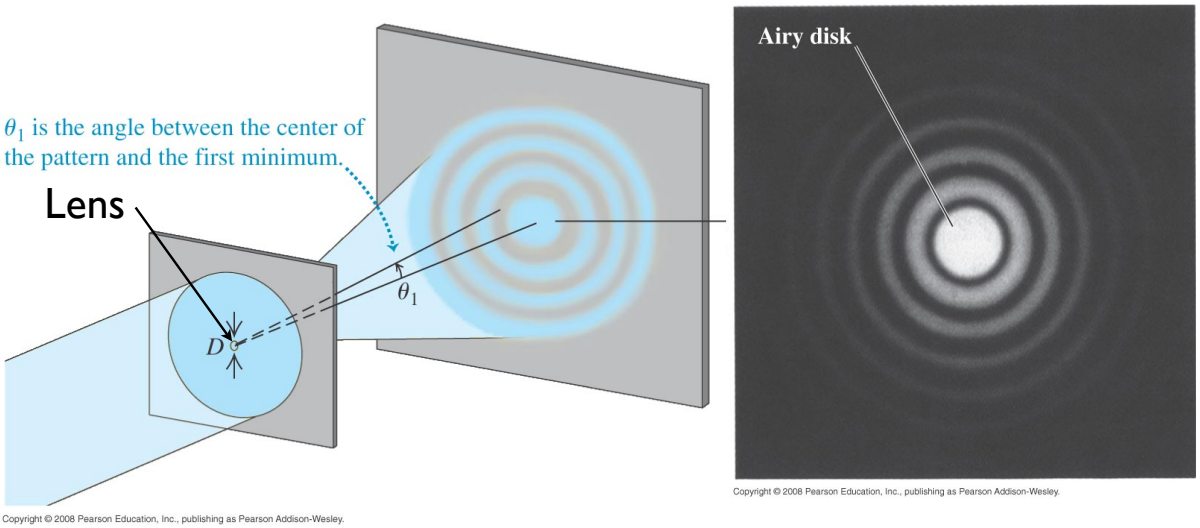


A. λ/2. B. λ/3.

C. λ/6. D. any of these.



Lens- Circular Aperture



$$\sin(\theta_1) = 1.22\frac{\lambda}{D}$$

Clicker Question

What is more important in a telescope or microscope:

A) Magnification
B) Resolution

Clicker Question

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B) Resolution

Clicker Question

What is more important in a telescope or microscope:

A) Magnification

B) Resolution

Provided the pixel separation in the detector can resolve the separation

Clicker Question

You use a telescope lens to form an image of two closely-spaced, distant stars. Which of the following will increase the resolving power?

A) Use a filter so that only the blue light from the stars enters the lens.

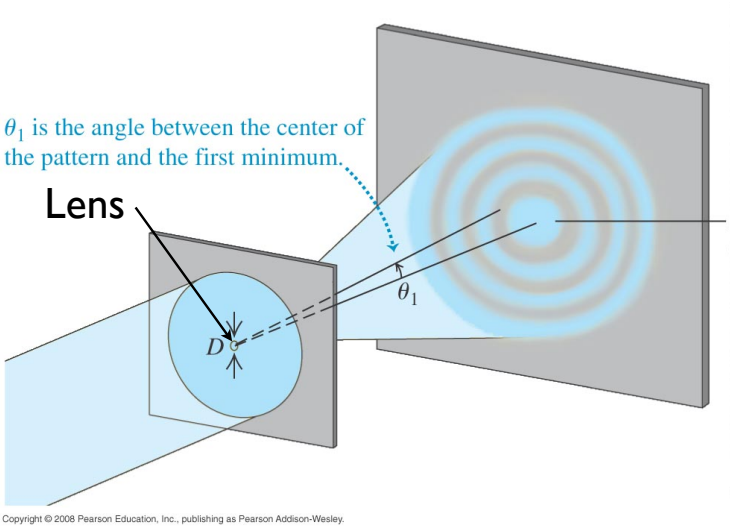
B) Use a filter so that only the red light from the stars enters the lens.

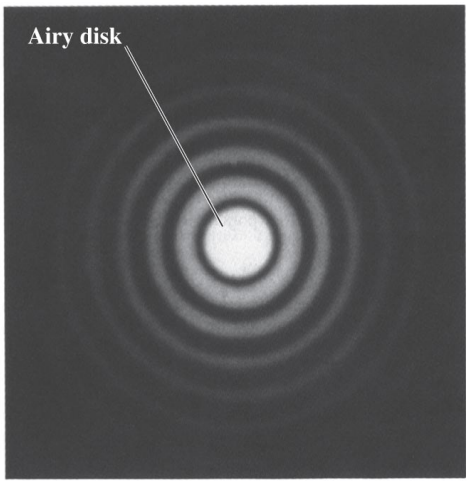
C) Use a lens of smaller diameter.

D) more than one of the above

Lecture 19

Lens- Circular Aperture





$$\sin(\theta_1) = 1.22\frac{\lambda}{D}$$

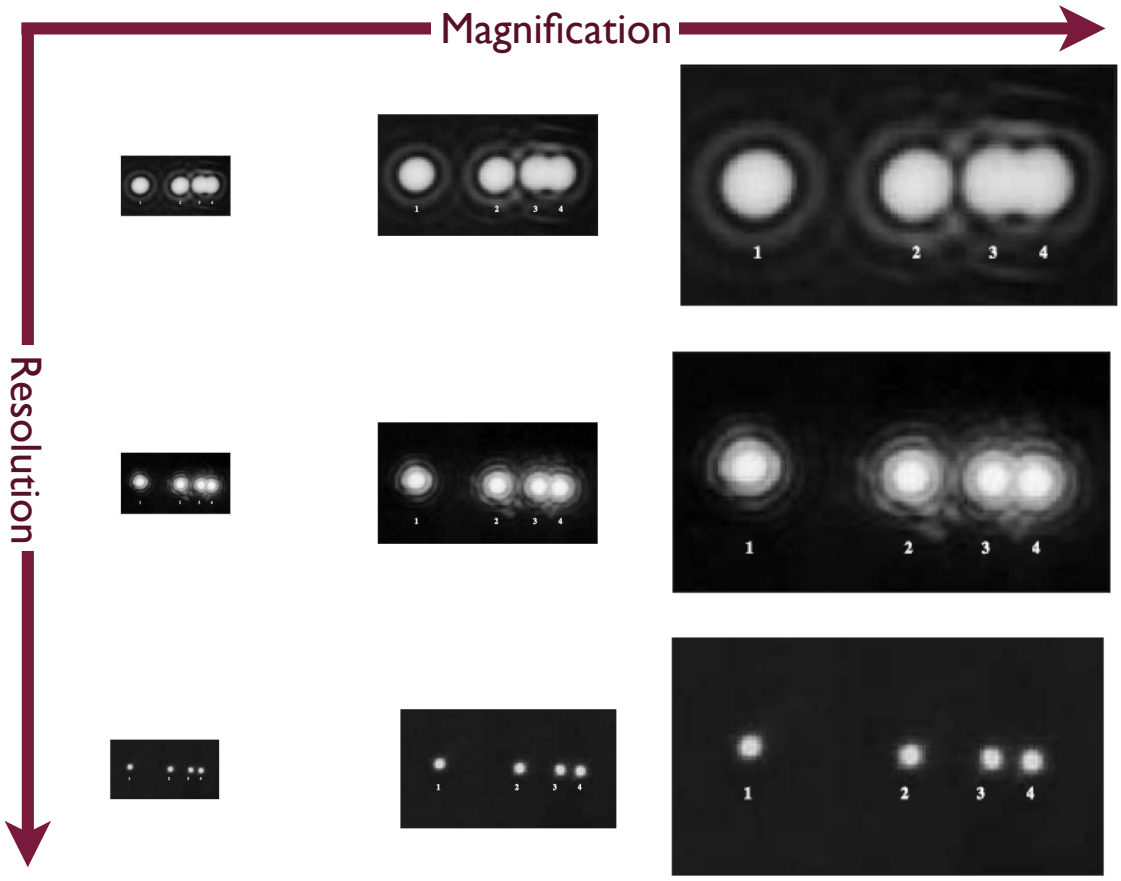


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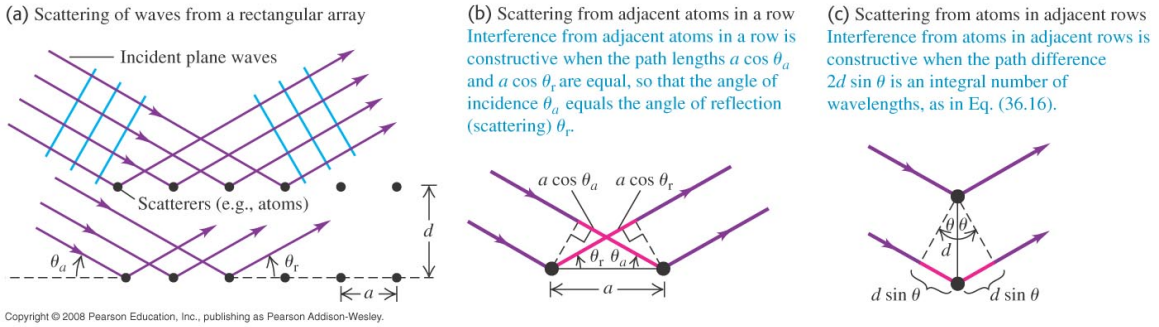
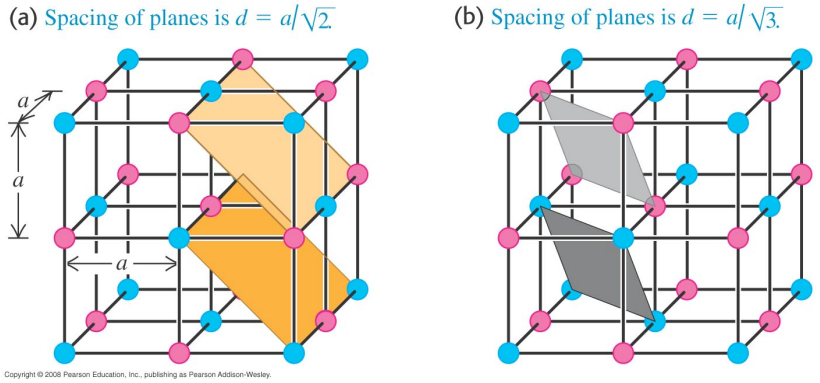
Figure 36.23





Clicker Question

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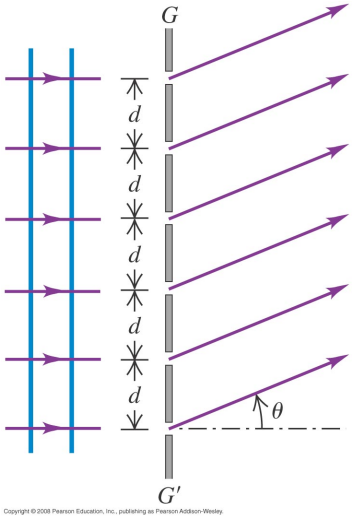

A. $\lambda/2$.

B. $\lambda/3$.

C. $\lambda/6$.

D. any of these.

Clicker Question

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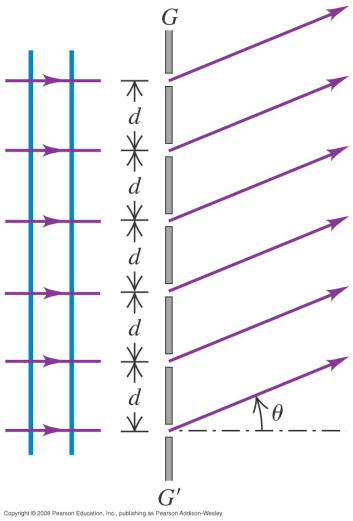


A. λ/2.

B. λ/3.

C. λ/6.

D. any of these.

Clicker Question

Diffraction occurs when light passes a:

A) pinhole

B) narrow slit

C) wide slit

D) sharp edge

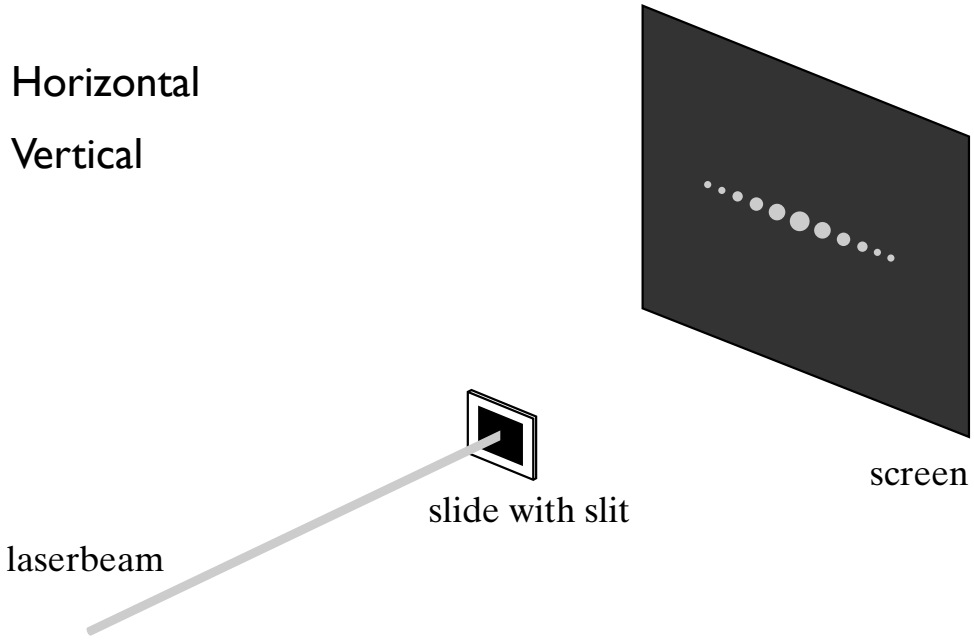
E) all of the above

Clicker Question

The pattern on the screen is due to a narrow slit that is

A) Horizontal

B) Vertical



Clicker Question

Light of wavelength λ passes through a single slit of width a. The diffraction pattern is observed on a screen that is very far from from the slit.

Which of the following will give the greatest increase in the angular width of the central diffraction maximum?

A) Double the slit width a and double the wavelength λ.

B) Double the slit width a and halve the wavelength λ.

C) Halve the slit width a and double the wavelength λ.

D) Halve the slit width a and halve the wavelength λ.

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Clicker Question

Blue light of wavelength λ passes through a single slit of width *a* and forms a diffraction pattern on a screen. If the blue light is replaced by red light of wavelength 2λ, the original diffraction pattern is reproduced if the slit width is changed to

A) *a*/4

B) *a*/2

C) No change is necessary.

D) 2*a*

E) 4*a*

Clicker Question

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A) *a*/4

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C) No change is necessary.

D) 2*a*

E) 4*a*

Clicker Question

For single slit diffraction, what will happen to the separation between the first dark fringes get larger or smaller if the slit width is made larger?

A) The separation will become larger

B) The separation will become smaller

C) The separation will remain the same

Clicker Question

For single slit diffraction, what will happen to the separation between the first dark fringes get larger or smaller if the slit width is made larger?

A) The separation will become larger

B) The separation will become smaller

C) The separation will remain the same

Clicker Question

In a single-slit diffraction experiment with waves of wavelength λ, there will be *no* intensity minima (that is, no dark fringes) if the slit width is small enough.

What is the *maximum* slit width a for which this occurs?

A. $a = \lambda/2$

B. $a = \lambda$

C. $a = 2\lambda$

D. The answer depends on the distance from the slit to the screen on which the diffraction pattern is viewed.

Clicker Question

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What is the *maximum* slit width a for which this occurs?

A. $a = \lambda/2$

B. $a = \lambda$

C. $a = 2\lambda$

D. The answer depends on the distance from the slit to the screen on which the diffraction pattern is viewed.

Clicker Question

In Young's experiment, coherent light passing through two slits separated by a distance d produces a pattern of dark and bright areas on a distant screen.
If instead you use 10 slits, each the same distance d from its neighbor, how does the pattern change?

A) The bright areas move farther apart.

B) The bright areas move closer together.

C) The spacing between bright areas remains the same, but the bright areas become narrower.

D) The spacing between bright areas remains the same, but the bright areas become broader.

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Clicker Question

In an x-ray diffraction experiment using a crystal, a pattern of bright spots is formed by

A) interference of x-rays scattered by different atoms in the crystal.

B) interference of x-rays emitted by different atoms in the crystal.

C) interference of x-rays scattered by different parts of an individual atom in the crystal.

D) interference of x-rays emitted by different parts of an individual atom in the crystal.

Clicker Question

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C) interference of x-rays scattered by different parts of an individual atom in the crystal.

D) interference of x-rays emitted by different parts of an individual atom in the crystal.

Lecture 20

Clicker Question

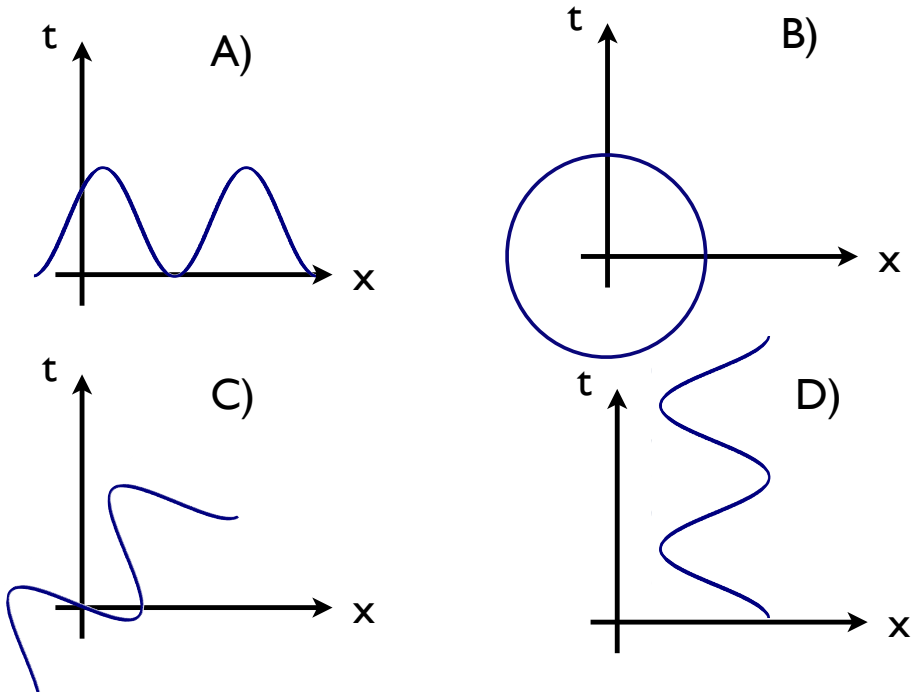
A)

B)

C)

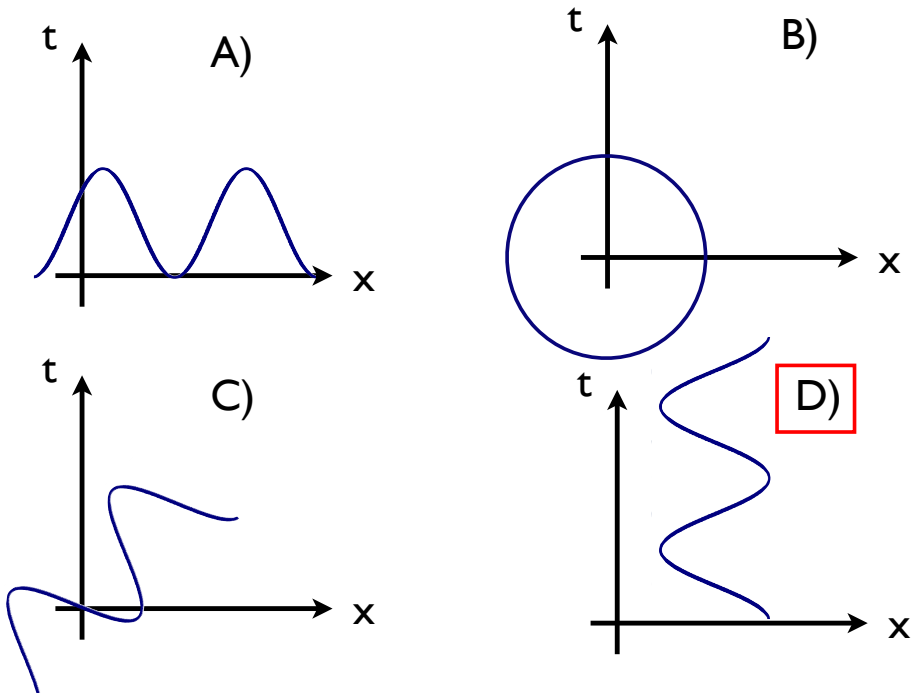
D)

Which spacetime diagram is most appropriate for an ideal pendulum?



Clicker Question

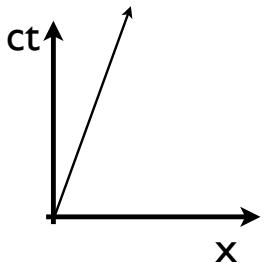
Which spacetime diagram is most appropriate for an ideal pendulum?



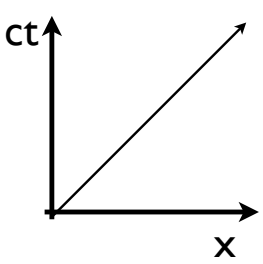
Clicker Question

Which Spacetime Diagram shows the worldline of light?

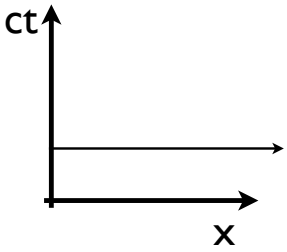
a)



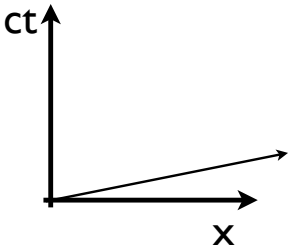
c)



c)



d)



Clicker Question

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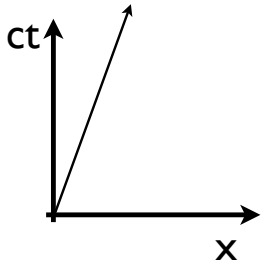
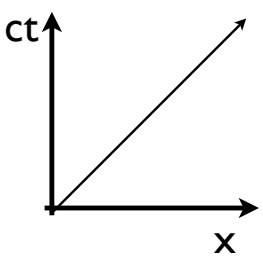
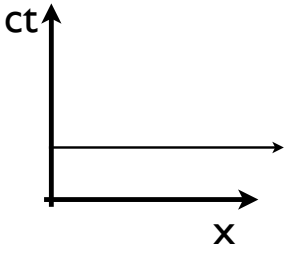


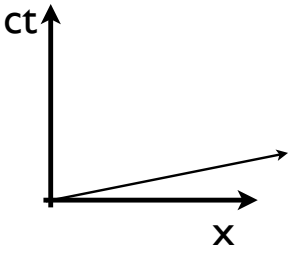
c)



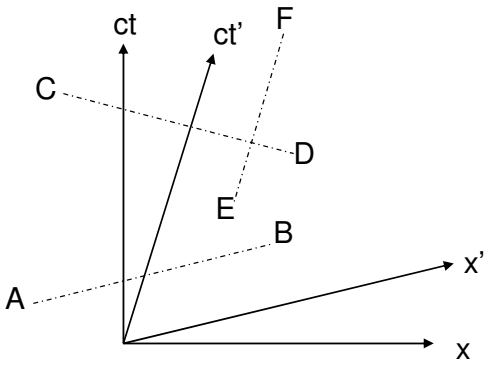
c)



d)



Clicker Question



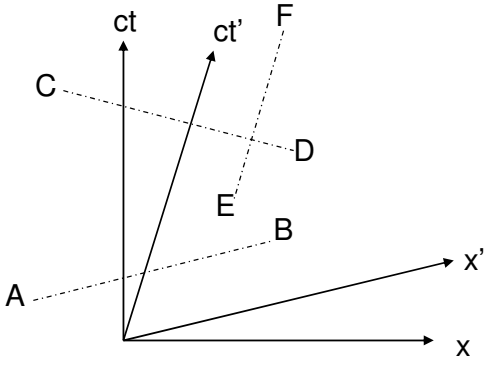
Which line could represent a set of synchronized clocks in the spaceship frame?

a) AB

b) CD

c) EF

Clicker Question



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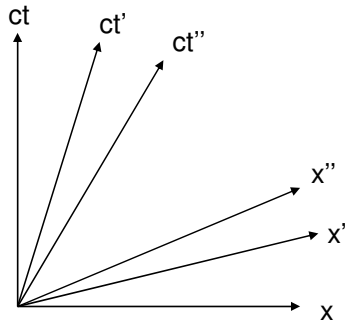


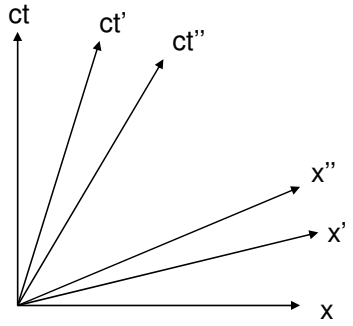
Which coordinate system represents the fastest moving inertial frame with respect to the lab frame?

a) un-primed

b) primed

c) double primed

Clicker Question



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■ **EXAMPLE 1.** An automobile collision occurs at exactly 10h 0m 0s Eastern Standard Time in Philadelphia, and another automobile collision occurs at exactly 10h 0m 0s in Boston, at a distance of 430 km from the first collision. The collisions are simultaneous in the reference frame of the Earth. What is the time difference between these collisions as measured in the reference frame of a spaceship traveling at $V = 0.9c$ in the direction from Philadelphia to Boston?

SOLUTION. Assume that the x axis is aligned with the two cities, with Philadelphia at $x_1 = 0$, and Boston at $x_2 = 4.3 \times 10^5$ m. In the reference frame of the Earth, the collisions occur simultaneously at $t_1 = t_2 = 10$ h. In the reference frame of the spaceship, they occur at

$$t_1' = \frac{t_1 - Vx_1/c^2}{\sqrt{1 - V^2/c^2}} = \frac{t_1}{\sqrt{1 - V^2/c^2}}$$

and at

$$t_2' = \frac{t_2 - Vx_2/c^2}{\sqrt{1 - V^2/c^2}} = \frac{t_1 - Vx_2/c^2}{\sqrt{1 - V^2/c^2}}$$

The time difference is

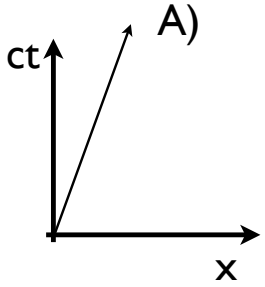
$$t_2' - t_1' = -\frac{Vx_2/c^2}{\sqrt{1 - V^2/c^2}} = -\frac{0.9 \times 4.3 \times 10^5 \text{ m}/(3 \times 10^8 \text{ m/s})}{\sqrt{1 - 0.9^2}} = -3.0 \times 10^{-3} \text{ s}$$

Lecture 21

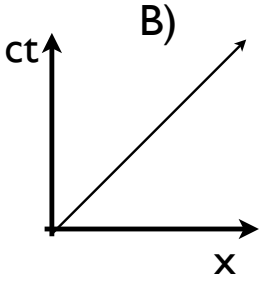
Clicker Question

Which Spacetime Diagram most accurately shows the worldline of light?

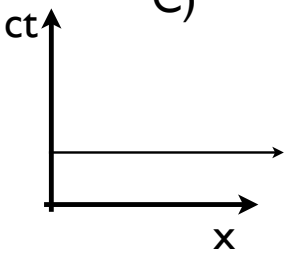
A)



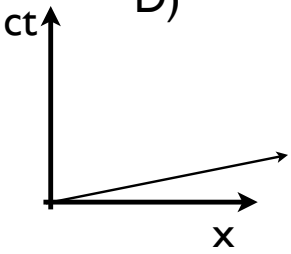
B)



C)



D)



Clicker Question

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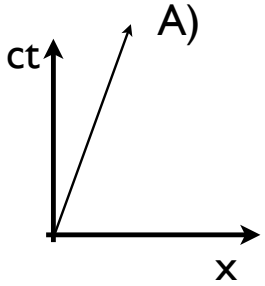
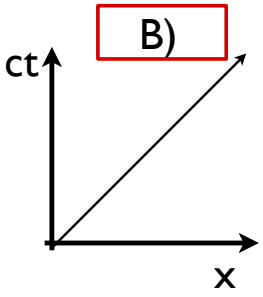
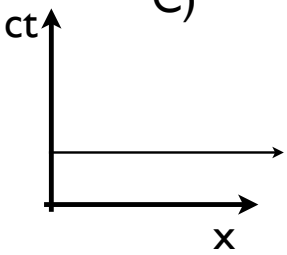


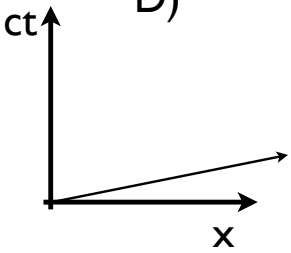
B)



C)



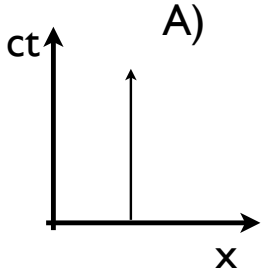
D)



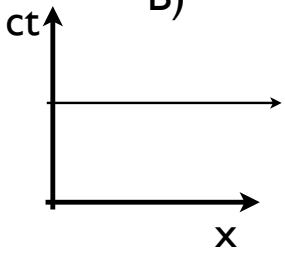
Clicker Question

Which Spacetime Diagram shows the worldline of an object moving with constant nonzero velocity?

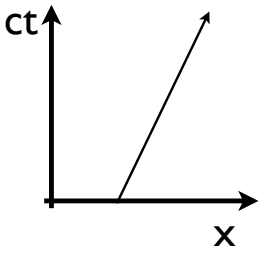
A)



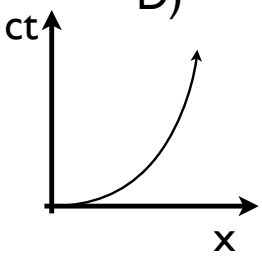
B)



C)



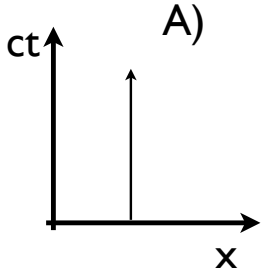
D)



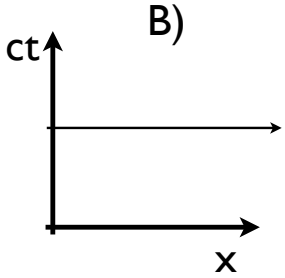
Clicker Question

Which Spacetime Diagram shows the worldline of an object moving with constant nonzero velocity?

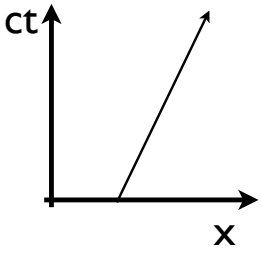
A)



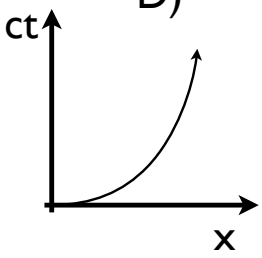
B)



C)



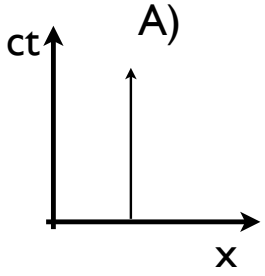
D)



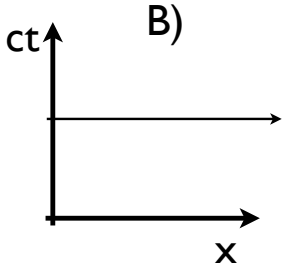
Clicker Question

Which Spacetime Diagram shows the worldline of an accelerating object?

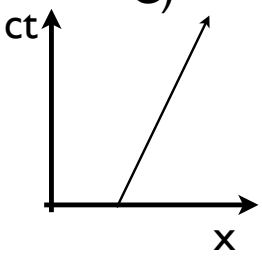
A)



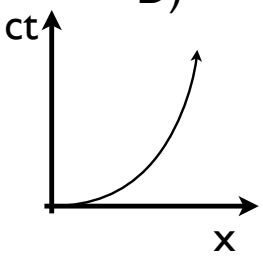
B)



C)



D)



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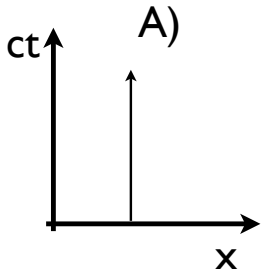
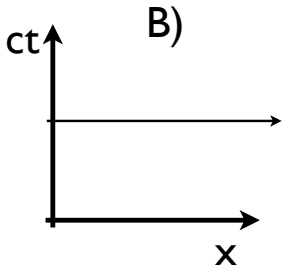
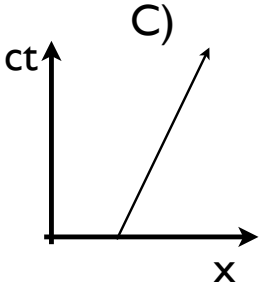


B)



C)



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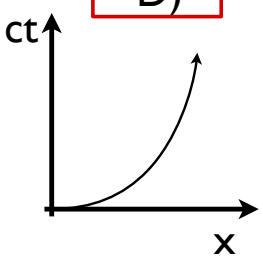


Clicker Question

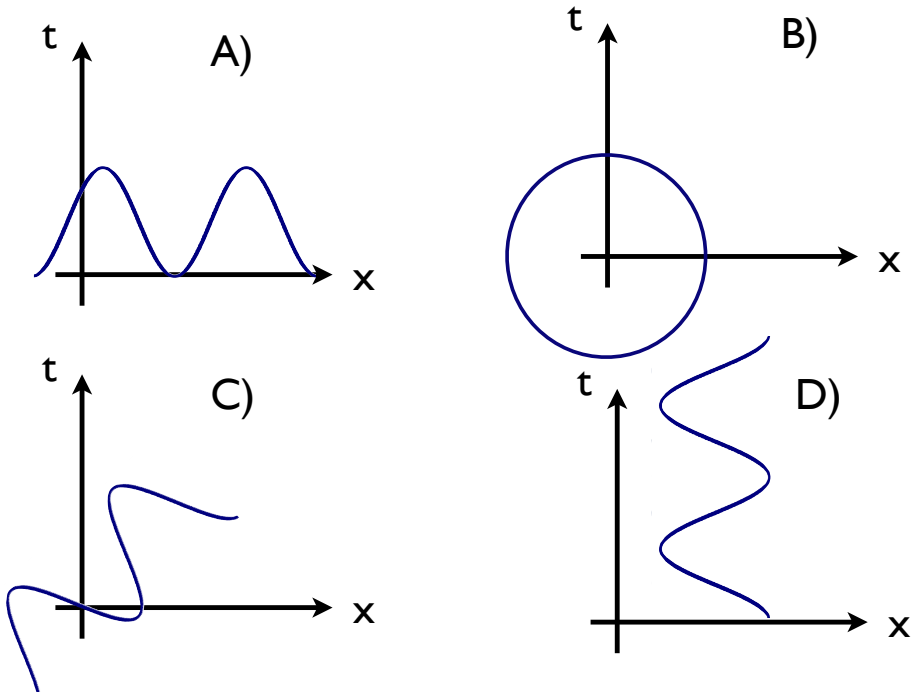
A)

B)

C)

D)

Which spacetime diagram is most appropriate for an ideal pendulum?



Clicker Question

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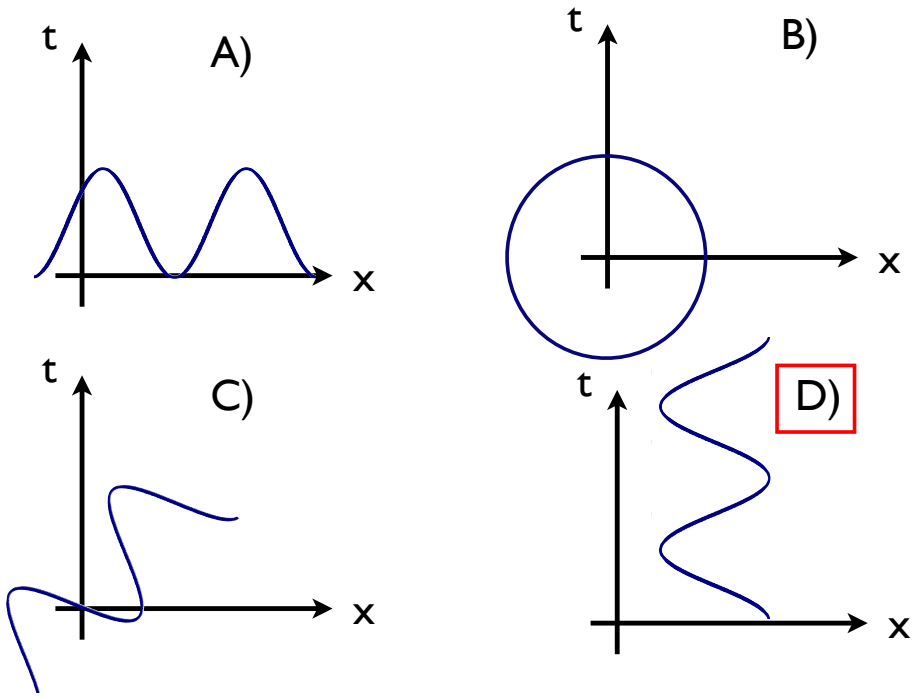
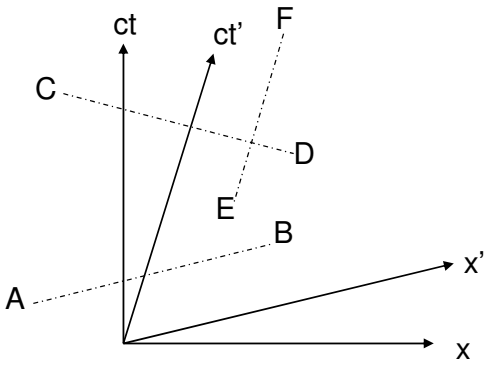


Clicker Question



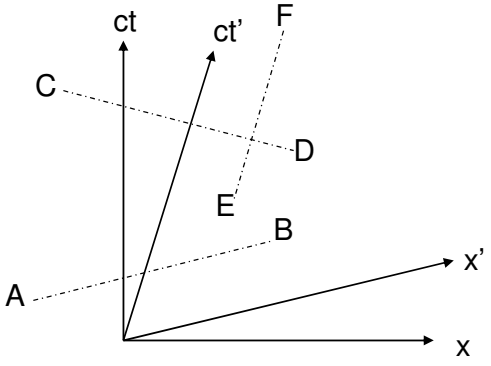
Which line could represent a set of synchronized clocks in the spaceship frame?

a) AB

b) CD

c) EF

Clicker Question



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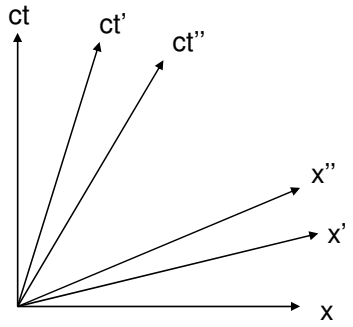


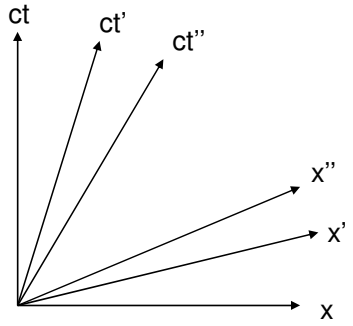
Which coordinate system represents the fastest moving inertial frame with respect to the lab frame?

a) un-primed

b) primed

c) double primed

Clicker Question



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■ **EXAMPLE 1.** An automobile collision occurs at exactly 10h 0m 0s Eastern Standard Time in Philadelphia, and another automobile collision occurs at exactly 10h 0m 0s in Boston, at a distance of 430 km from the first collision. The collisions are simultaneous in the reference frame of the Earth. What is the time difference between these collisions as measured in the reference frame of a spaceship traveling at $V = 0.9c$ in the direction from Philadelphia to Boston?

SOLUTION. Assume that the x axis is aligned with the two cities, with Philadelphia at $x_1 = 0$, and Boston at $x_2 = 4.3 \times 10^5$ m. In the reference frame of the Earth, the collisions occur simultaneously at $t_1 = t_2 = 10$ h. In the reference frame of the spaceship, they occur at

$$t_1' = \frac{t_1 - Vx_1/c^2}{\sqrt{1 - V^2/c^2}} = \frac{t_1}{\sqrt{1 - V^2/c^2}}$$

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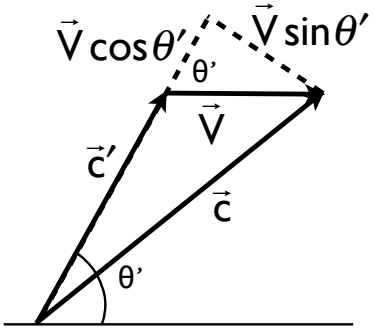
The time difference is

$$t_2' - t_1' = -\frac{Vx_2/c^2}{\sqrt{1 - V^2/c^2}} = -\frac{0.9 \times 4.3 \times 10^5 \text{ m}/(3 \times 10^8 \text{ m/s})}{\sqrt{1 - 0.9^2}} = -3.0 \times 10^{-3} \text{ s}$$

Lecture 22

13. Consider a reference frame moving with uniform velocity V through the ether. A light signal travels at angle θ' with respect to the direction of V. Show that according to the Galilean addition law for velocities, light in the reference frame has a speed given by:

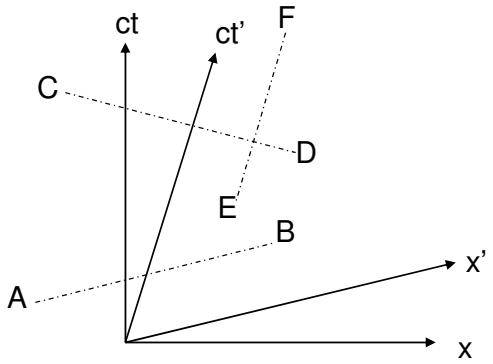
$$c' = \sqrt{c^2 - V^2 \sin^2\theta'} - V\cos\theta'$$



$$c^2 = V^2\sin^2\theta' + \left(c' + V\cos\theta'\right)^2$$

$$\left(c' + V\cos\theta'\right)^2 = c^2 - V^2\sin^2\theta'$$

Clicker Question



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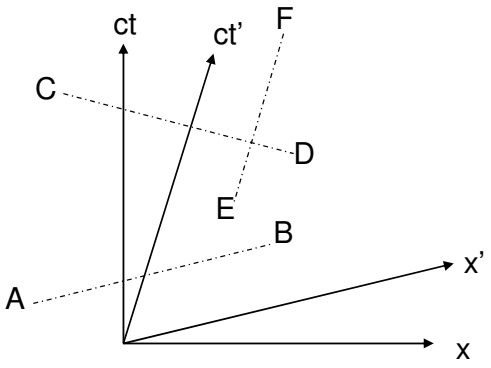

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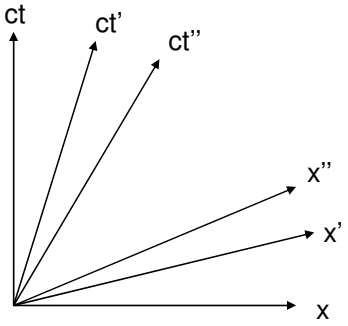

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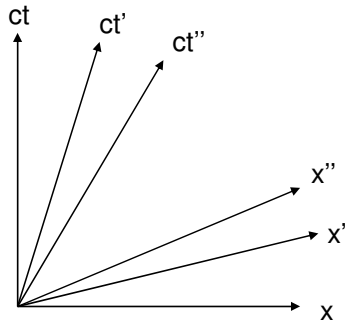

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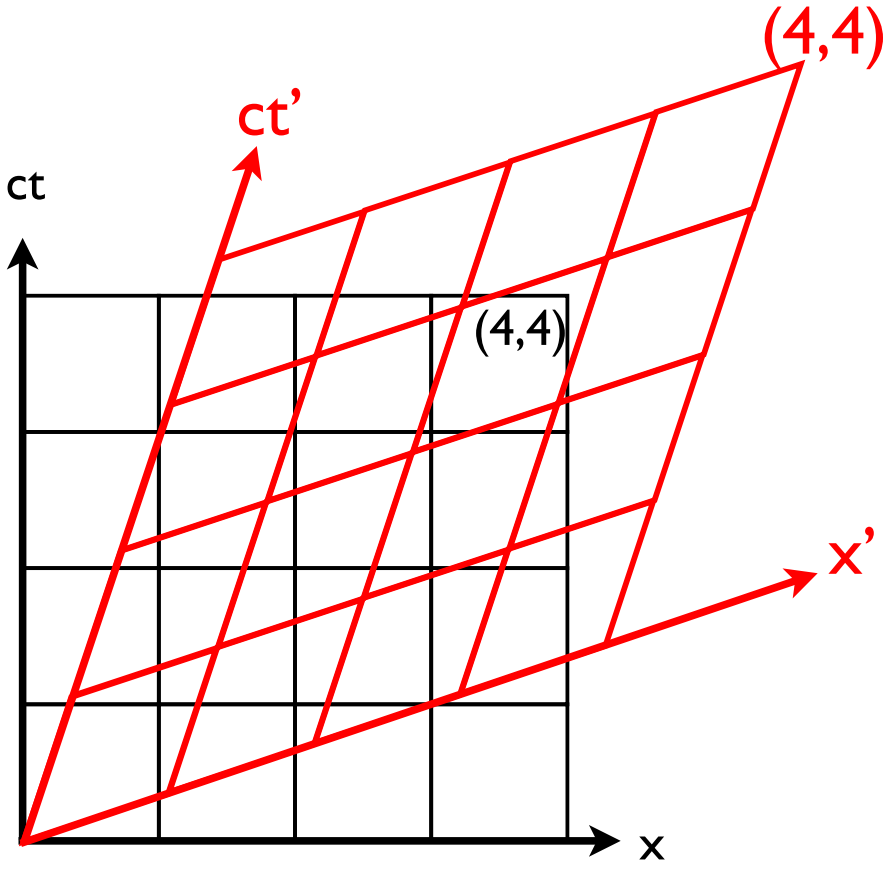

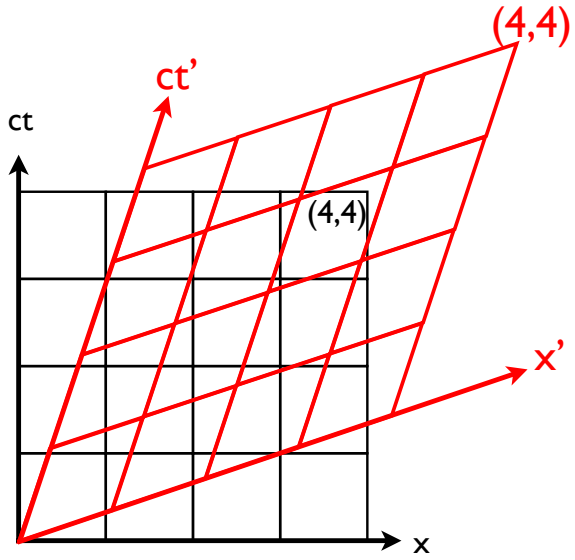

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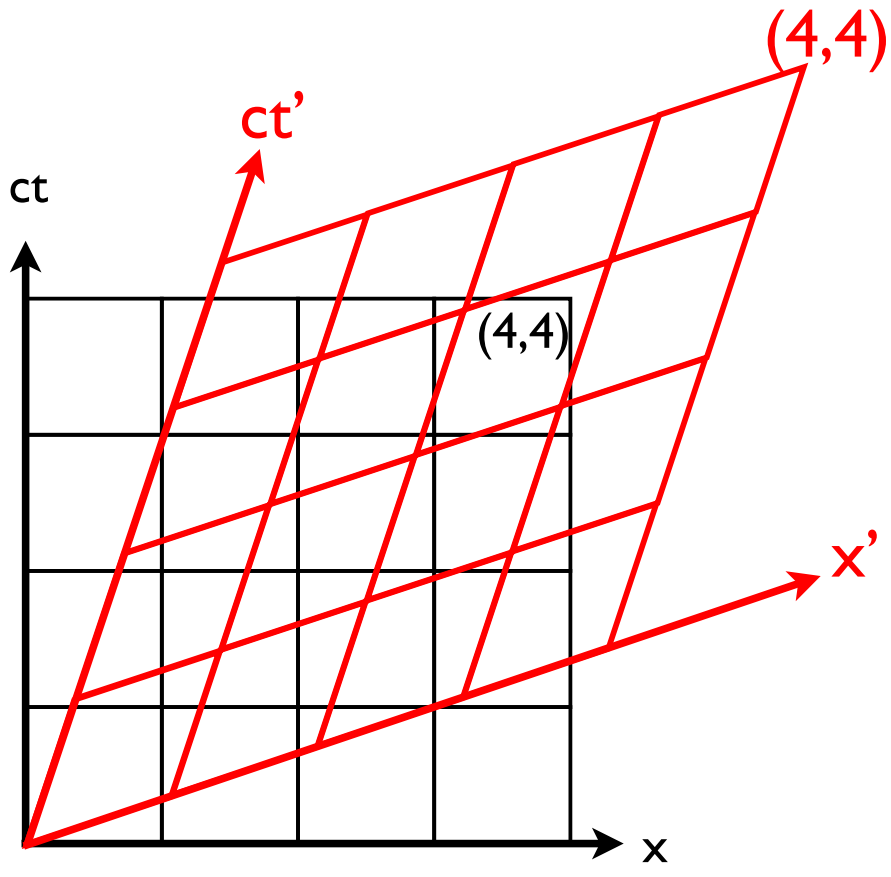
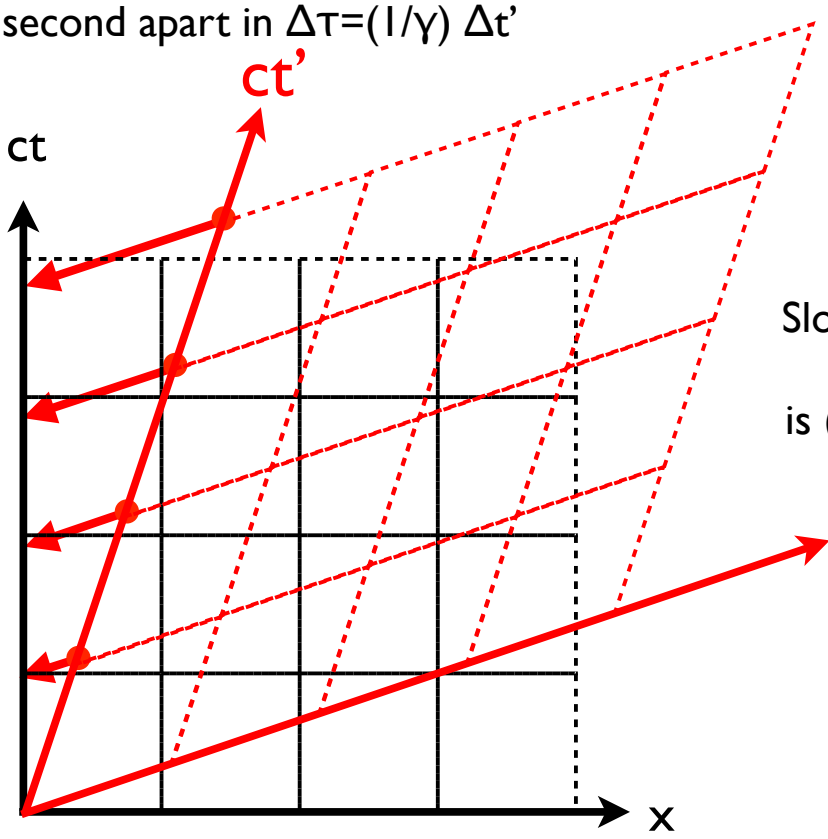
Lecture 23

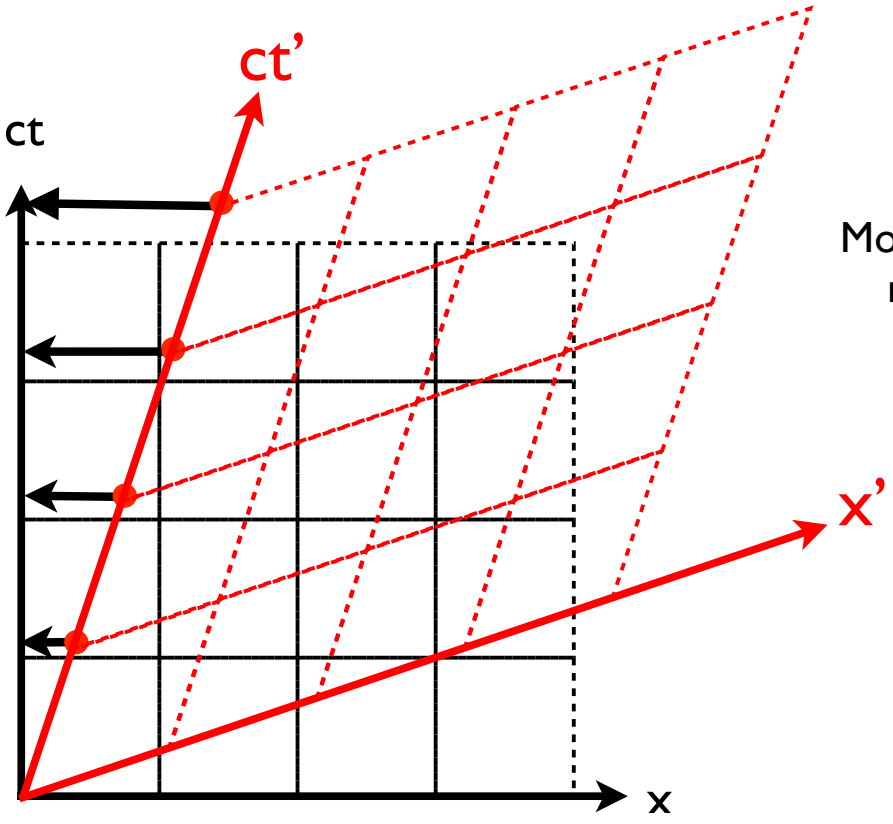


Proper Time: Events that are 1 second apart in S' are less than 1 second apart in $\Delta\tau=(1/\gamma)\,\Delta t'$



Slow-Motion:
1 s in S'
is $(1/\gamma)$ s in S

Time Dilation: Events that are spaced 1 second apart in S' are are spaced more than 1 second apart in S ($\Delta ct=(\gamma)\,\Delta ct'$)



Moving clocks
run slow

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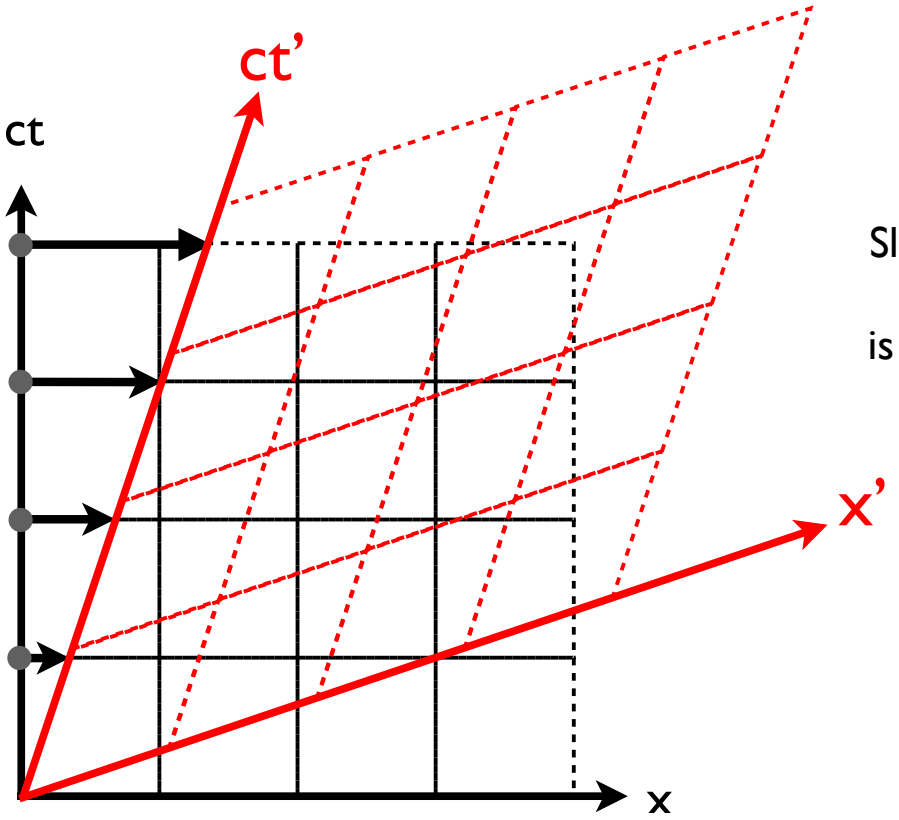

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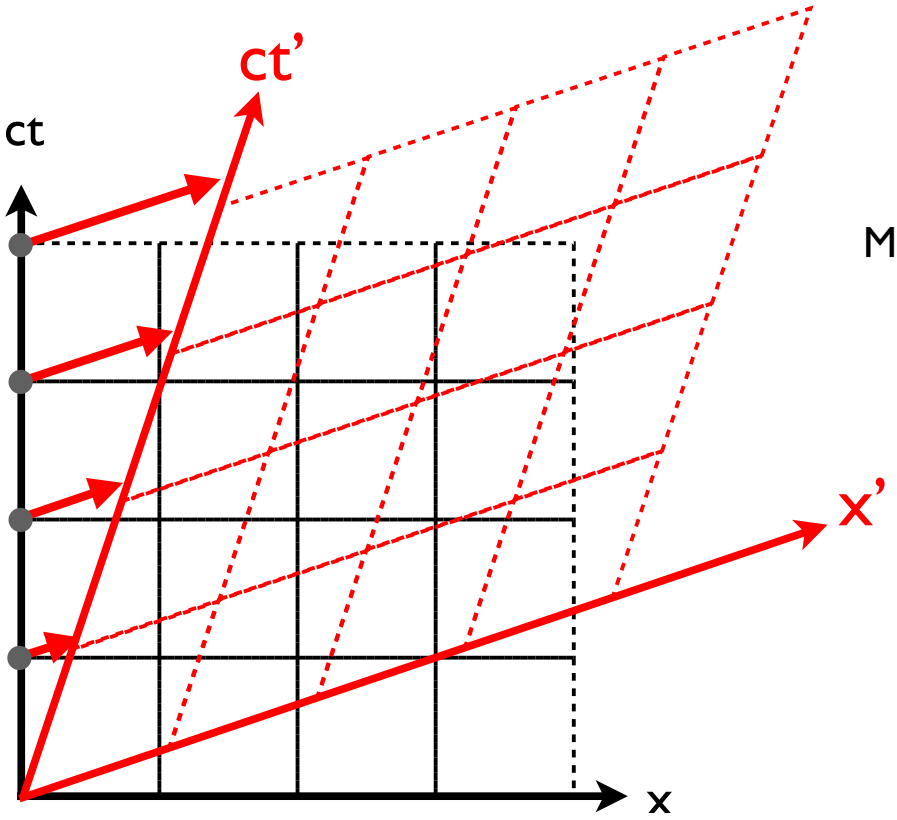

Moving clocks
run slow

Clicker Question

A spaceship is traveling past the earth at nearly the speed of light. The crew on board watches 1 minute elapse on a stop watch. From earth, if we could see the stop watch, how long did it take for the watch to elapse 1 minute?

A) 1 minute.

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Clicker Question

In the 'muon experiment,' will special relativity predict a difference in the ratio of muons that reach the ground, as compared to non-relativistic calculations?

A) Special Relativity will predict more muons reach the ground.

B) Special Relativity will predict the same number of muons reach the ground.

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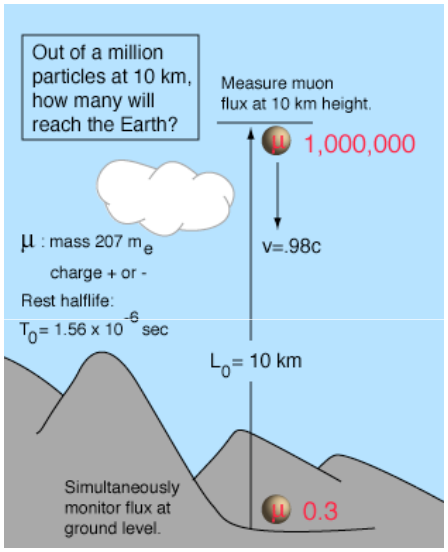

non-relativistic

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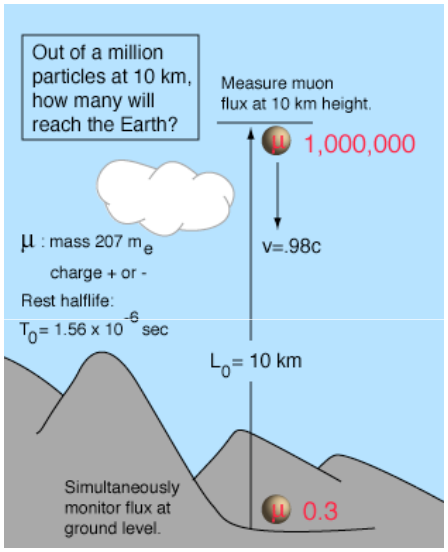
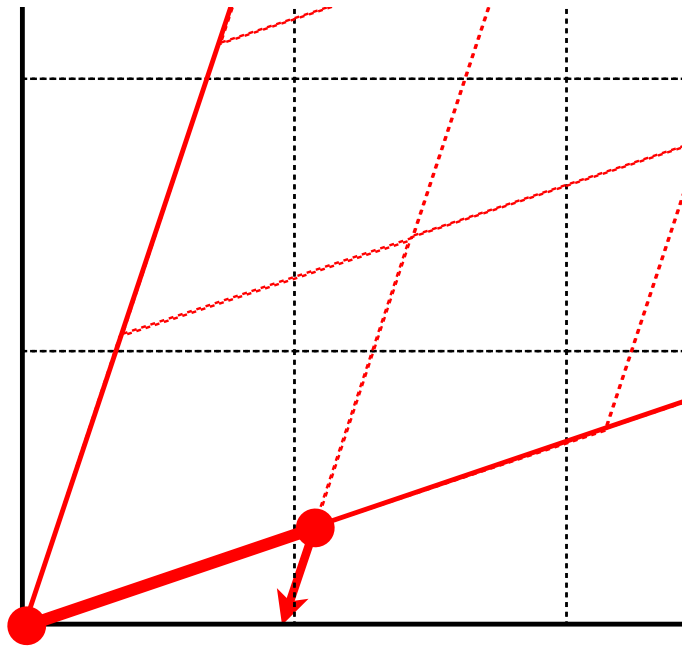


non-relativistic

Length Contraction: Objects that are 1 meter long in S' appear less than 1 meter long in S ($\Delta x=(1/\gamma)\,\Delta x'$)



Length measurements must be made <u>at the same time</u> in an IRF

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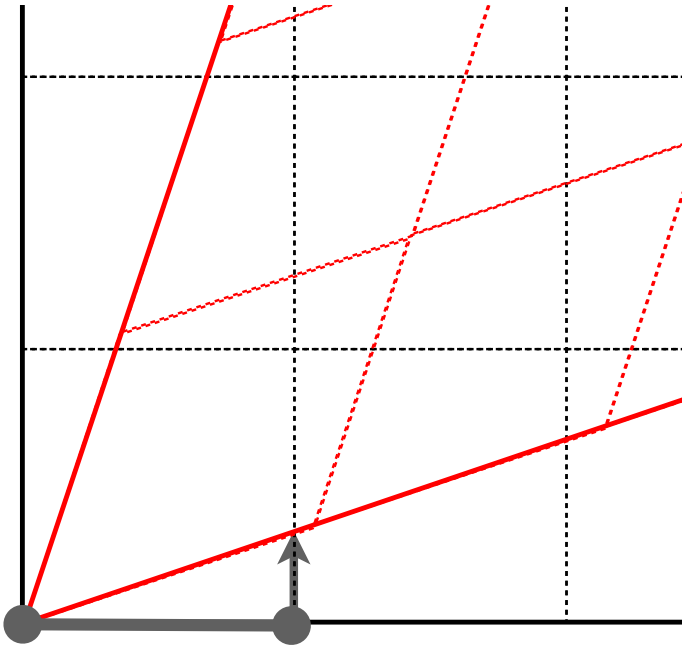

Length measurements must be made <u>at the same time</u> in an IRF

Clicker Question

Terra (who is standing on the ground) starts his stopwatch at the instant that Stella flies past him in her spaceship.

Later, according to Stella, at the instant that Terra's stopwatch reads 8.0 s, Stella's stopwatch reads 10.0 s.

According to *Stella*, her spaceship is 100 m long (along the direction of motion). According to *Terra*, the length of Stella's spaceship is:

A) 64 m.

B) 80 m.

C) 100 m.

D) 125 m.

E) none of the above

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According to Stella, at the instant that Terra's stopwatch reads 16.0 s, Stella's stopwatch reads 20.0 s.

According to *Terra*, at the instant that *Stella's* stopwatch reads 20.0 s, *Terra's* stopwatch reads:

A. 16.0 s.

B. 20.0 s.

C. 25.0 s.

D. none of the above

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