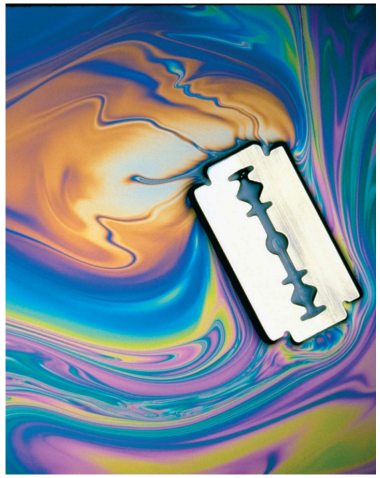
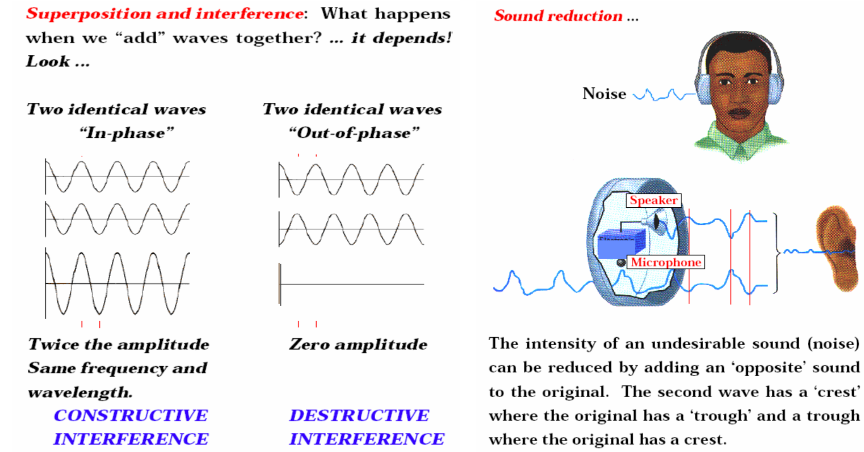
Chapter 21. Superposition

The combination of two or more waves is called a *superposition* of waves. Applications of superposition range from musical instruments to the colors of an oil film to lasers.

Chapter Goal: To understand and use the idea of superposition.



Chapter 21. Superposition

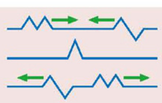


Principal of superposition

GENERAL PRINCIPLES

Principle of Superposition

The displacement of a medium when more than one wave is present is the sum of the displacements due to each individual wave.



Superimposed → Superposition

$$D_{net} = D_1 + D_2 + \ldots + D_N = \sum_{i=1}^{N} D_i$$

Chapter 21. Superposition

Topics:

- The Principle of Superposition
- Standing Waves
- Transverse Standing Waves
- Standing Sound Waves and Musical Acoustics
- Interference in One Dimension
- The Mathematics of Interference
- Interference in Two and Three Dimensions
- Beats

Chapter 21. Reading Quizzes

When a wave pulse on a string reflects from a hard boundary, how is the reflected pulse related to the incident pulse?

A. Shape unchanged, amplitude unchanged
B. Shape inverted, amplitude unchanged
C. Shape unchanged, amplitude reduced
D. Shape inverted, amplitude reduced
E. Amplitude unchanged, speed reduced

When a wave pulse on a string reflects from a hard boundary, how is the reflected pulse related to the incident pulse?

A. Shape unchanged, amplitude unchanged
✔ **B. Shape inverted, amplitude unchanged**
C. Shape unchanged, amplitude reduced
D. Shape inverted, amplitude reduced
E. Amplitude unchanged, speed reduced

There are some points on a standing wave that never move. What are these points called?

A. Harmonics
B. Normal Modes
C. Nodes
D. Anti-nodes
E. Interference

There are some points on a standing wave that never move. What are these points called?

A. Harmonics
B. Normal Modes
✔ **C. Nodes**
D. Anti-nodes
E. Interference

Two sound waves of nearly equal frequencies are played simultaneously. What is the name of the acoustic phenomena you hear if you listen to these two waves?

A. Beats
B. Diffraction
C. Harmonics
D. Chords
E. Interference

Two sound waves of nearly equal frequencies are played simultaneously. What is the name of the acoustic phenomena you hear if you listen to these two waves?

✔ **A. Beats**
B. Diffraction
C. Harmonics
D. Chords
E. Interference

The various possible standing waves on a string are called the

A. antinodes.
B. resonant nodes.
C. normal modes.
D. incident waves.

The various possible standing waves on a string are called the

A. antinodes.
B. resonant nodes.
✔ **C. normal modes.**
D. incident waves.

The frequency of the third harmonic of a string is

A. one-third the frequency of the fundamental.
B. equal to the frequency of the fundamental.
C. three times the frequency of the fundamental.
D. nine times the frequency of the fundamental.

The frequency of the third harmonic of a string is

A. one-third the frequency of the fundamental.
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D. nine times the frequency of the fundamental.

Chapter 21. Basic Content and Examples

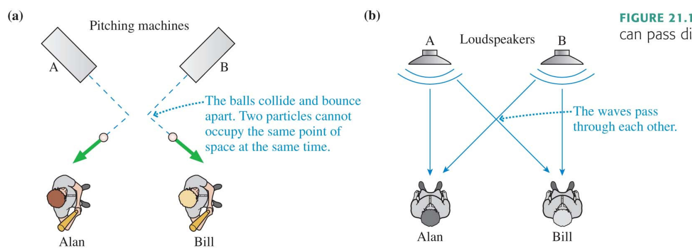


FIGURE 21.1 Unlike particles, two waves can pass directly through each other.

The Principle of Superposition

If wave 1 displaces a particle in the medium by D_1 and wave 2 simultaneously displaces it by D_2, the net displacement of the particle is simply $D_1 + D_2$.

Principle of superposition When two or more waves are *simultaneously* present at a single point in space, the displacement of the medium at that point is the sum of the displacements due to each individual wave.

Standing Waves

FIGURE 21.3 A vibrating string is an example of a standing wave.

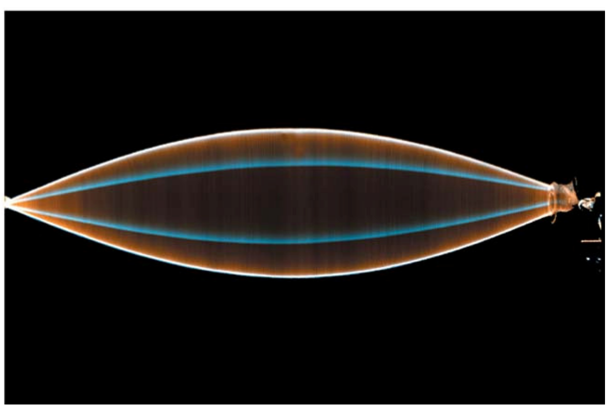
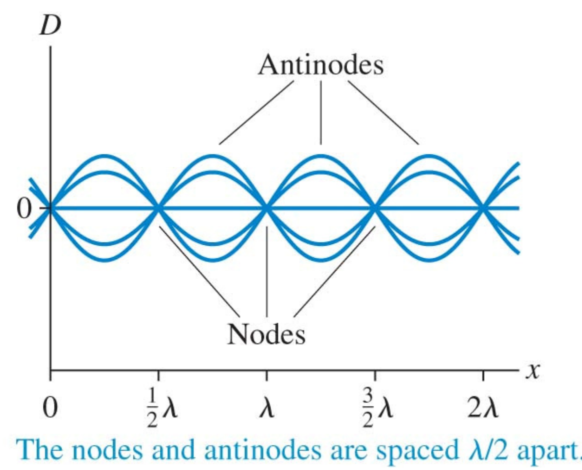


FIGURE 21.5 Standing waves are often represented as they would be seen in a time-lapse photograph.



The Mathematics of Standing Waves

A sinusoidal wave traveling to the right along the *x*-axis with angular frequency $\omega = 2\pi f$, wave number $k = 2\pi/\lambda$ and amplitude a is

$$D_R = a\sin(kx - \omega t)$$

An equivalent wave traveling to the left is

$$D_L = a\sin(kx + \omega t)$$

We previously used the symbol A for the wave amplitude, but here we will use a lowercase a to represent the amplitude of each individual wave and reserve A for the amplitude of the net wave.

The Mathematics of Standing Waves

According to the principle of superposition, the net displacement of the medium when both waves are present is the sum of D_R and D_L:

$$D(x, t) = D_R + D_L = a\sin(kx - \omega t) + a\sin(kx + \omega t)$$

We can simplify this by using a trigonometric identity, and arrive at

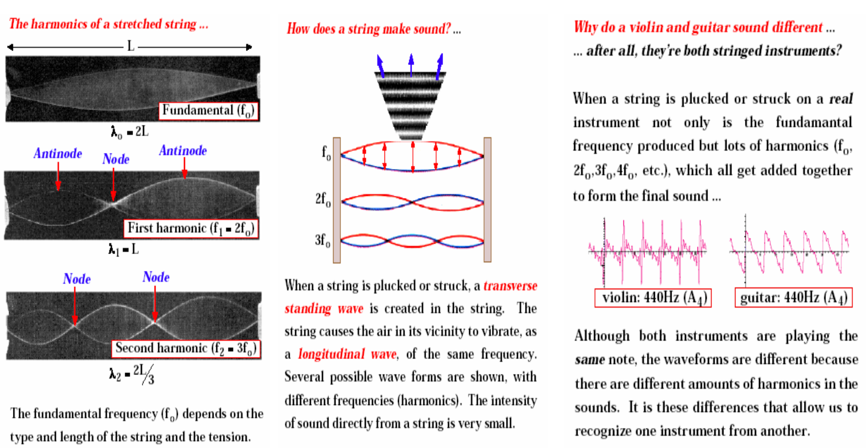
$$D(x, t) = a(\sin kx \cos\omega t - \cos kx \sin\omega t) + a(\sin kx \cos\omega t + \cos kx \sin\omega t)$$

Where the amplitude function $A(x)$ is defined as

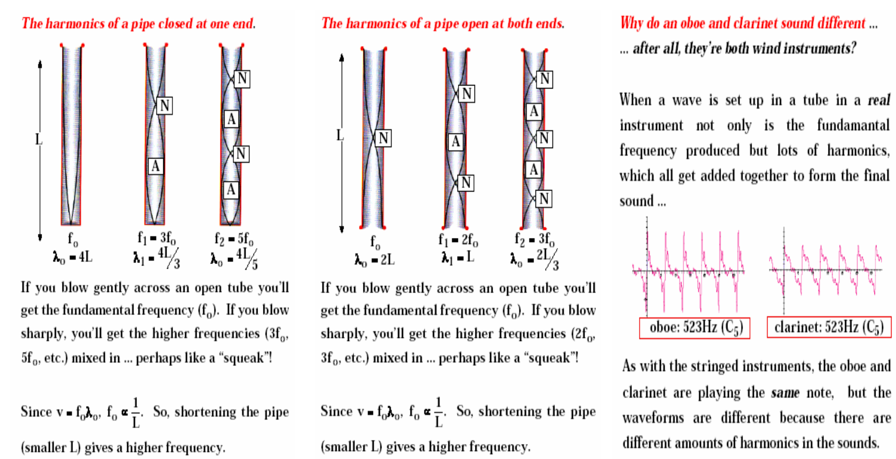
$$D(x, t) = A(x)\cos\omega t$$

The amplitude reaches a maximum value of $A_{max} = 2a$ at points where $\sin kx = 1$.

Examples: Waves on Strings



Examples: Waves on Pipes



EXAMPLE 21.1 Node spacing on a string

QUESTIONS:

EXAMPLE 21.1 Node spacing on a string

A very long string has a linear density of 5.0 g/m and is stretched with a tension of 8.0 N. 100 Hz waves with amplitudes of 2.0 mm are generated at the ends of the string.

a. What is the node spacing along the resulting standing wave?
b. What is the maximum displacement of the string?

EXAMPLE 21.1 Node spacing on a string

MODEL Two counter-propagating waves of equal frequency create a standing wave.

EXAMPLE 21.1 Node spacing on a string

VISUALIZE The standing wave will look like Figure 21.5.

EXAMPLE 21.1 Node spacing on a string

SOLVE a. The speed of the waves on the string is

$$v = \sqrt{\frac{T_s}{\mu}} = \sqrt{\frac{8.0\ \text{N}}{0.0050\ \text{kg/m}}} = 40\ \text{m/s}$$

and thus the wavelength is

$$\lambda = \frac{v}{f} = \frac{40\ \text{m/s}}{100\ \text{Hz}} = 0.40\ \text{m} = 40\ \text{cm}$$

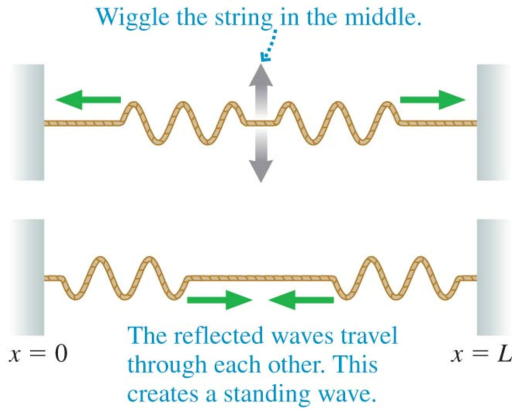
Thus the spacing between adjacent nodes is $\lambda/2 = 20$ cm.

b. The maximum displacement, at the antinodes, is

$$A_{max} = 2a = 4.0\ \text{mm}$$

Standing Waves on a String

FIGURE 21.10 Reflections at the two boundaries cause a standing wave on the string.



Standing Waves on a String

For a string of fixed length L, the boundary conditions can be satisfied only if the wavelength has one of the values

$$\lambda_m = \frac{2L}{m} \qquad m = 1, 2, 3, 4, \ldots$$

A standing wave can exist on the string *only* if its wavelength is one of the values given by Equation 21.13. Because $\lambda f = v$ for a sinusoidal wave, the oscillation frequency corresponding to wavelength λ_m is

$$f_m = \frac{v}{\lambda_m} = \frac{v}{2L/m} = m\frac{v}{2L} \qquad m = 1, 2, 3, 4, \ldots$$

Standing Waves on a String

There are three things to note about the normal modes of a string.

1. m is the number of *antinodes* on the standing wave, not the number of nodes. You can tell a string's mode of oscillation by counting the number of antinodes.
2. The *fundamental mode*, with $m = 1$, has $\lambda_1 = 2L$, not $\lambda_1 = L$. Only half of a wavelength is contained between the boundaries, a direct consequence of the fact that the spacing between nodes is $\lambda/2$.
3. The frequencies of the normal modes form a series: f_1, $2f_1$, $3f_1$, …The fundamental frequency f_1 can be found as the *difference* between the frequencies of any two adjacent modes. That is, $f_1 = \Delta f = f_{m+1} - f_m$.

EXAMPLE 21.4 Cold spots in a microwave oven

QUESTION:

EXAMPLE 21.4 Cold spots in a microwave oven
Cold spots in a microwave oven are found to be 6.0 cm apart. What is the frequency of the microwaves?

EXAMPLE 21.4 Cold spots in a microwave oven

MODEL A standing wave is created by microwaves reflecting from the walls.

EXAMPLE 21.4 Cold spots in a microwave oven

SOLVE The cold spots are nodes in the microwave standing wave. Nodes are spaced $\lambda/2$ apart, so the wavelength of the microwave radiation must be $\lambda = 12\text{ cm} = 0.12\text{ m}$. The speed of microwaves is the speed of light, $v = c$, so the frequency is

$$f = \frac{c}{\lambda} = \frac{3.00 \times 10^8\text{ m/s}}{0.12\text{ m}} = 2.5 \times 10^9\text{ Hz} = 2.5\text{ GHz}$$

Standing Sound Waves

- A long, narrow column of air, such as the air in a tube or pipe, can support a longitudinal standing sound wave.
- A closed end of a column of air must be a displacement node. Thus the boundary conditions—nodes at the ends—are the same as for a standing wave on a string.
- It is often useful to think of sound as a pressure wave rather than a displacement wave. The pressure oscillates around its equilibrium value.
- The nodes and antinodes of the pressure wave are interchanged with those of the displacement wave.

FIGURE 21.15 The $m = 2$ longitudinal standing wave can be represented as a displacement wave or as a pressure wave.

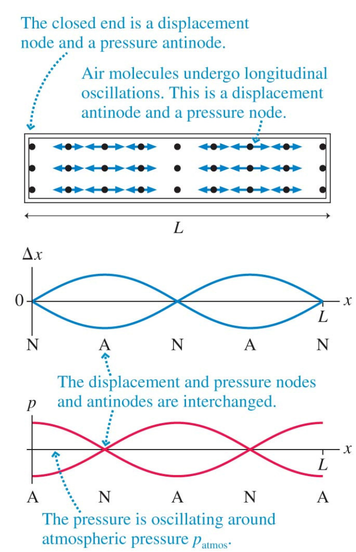
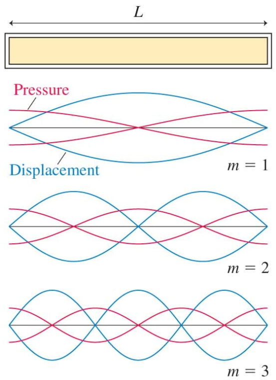


FIGURE 21.16 The first three standing sound wave modes in columns of air with different boundary conditions.

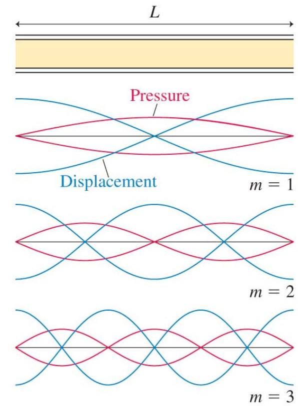
(a) Closed-closed



$$\begin{cases} \lambda_m = \dfrac{2L}{m} \\ f_m = m\dfrac{v}{2L} = mf_1 \end{cases} \qquad m = 1, 2, 3, 4, \ldots \quad \text{(open-open or closed-closed tube)}$$

FIGURE 21.16 The first three standing sound wave modes in columns of air with different boundary conditions.

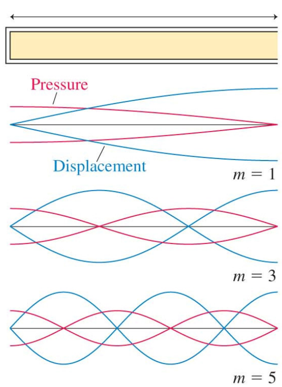
(b) Open-open



$$\begin{cases} \lambda_m = \dfrac{2L}{m} \\ f_m = m\dfrac{v}{2L} = mf_1 \end{cases} \qquad m = 1, 2, 3, 4, \ldots \quad \text{(open-open or closed-closed tube)}$$

FIGURE 21.16 The first three standing sound wave modes in columns of air with different boundary conditions.

(c) Open-closed



$$\begin{cases} \lambda_m = \dfrac{4L}{m} \\ f_m = m\dfrac{v}{4L} = mf_1 \end{cases} \qquad m = 1, 3, 5, 7, \ldots \quad \text{(open-closed tube)}$$

EXAMPLE 21.6 The length of an organ pipe

QUESTION:

EXAMPLE 21.6 The length of an organ pipe

An organ pipe open at both ends sounds its second harmonic at a frequency of 523 Hz. (Musically, this is the note one octave above middle C.) What is the length of the pipe from the sounding hole to the end?

EXAMPLE 21.6 The length of an organ pipe

MODEL An organ pipe, similar to a flute, has a *sounding hole* where compressed air is blown across the edge of the pipe. This is one end of an open-open tube, with the other end at the true "end" of the pipe. Assume a room-temperature (20°C) speed of sound.

EXAMPLE 21.6 The length of an organ pipe

SOLVE The second harmonic is the $m = 2$ mode, which for an open-open tube has frequency

$$f_2 = 2\frac{v}{2L}$$

Thus the length of the organ pipe is

$$L = \frac{v}{f_2} = \frac{343 \text{ m/s}}{523 \text{ Hz}} = 0.656 \text{ m} = 65.6 \text{ cm}$$

EXAMPLE 21.6 The length of an organ pipe

ASSESS This is a typical length for an organ pipe.

EXAMPLE 21.7 The notes on a clarinet

QUESTION:

EXAMPLE 21.7 The notes on a clarinet

A clarinet is 66.0 cm long. The speed of sound in warm air is 350 m/s. What are the frequencies of the lowest note on a clarinet and of the next highest harmonic?

EXAMPLE 21.7 The notes on a clarinet

MODEL A clarinet is an open-closed tube because the player's lips and the reed seal the tube at the upper end.

EXAMPLE 21.7 The notes on a clarinet

SOLVE The lowest frequency is the fundamental frequency. For an open-closed tube, the fundamental frequency is

$$f_1 = \frac{v}{4L} = \frac{350\text{ m/s}}{4(0.660\text{ m})} = 133\text{ Hz}$$

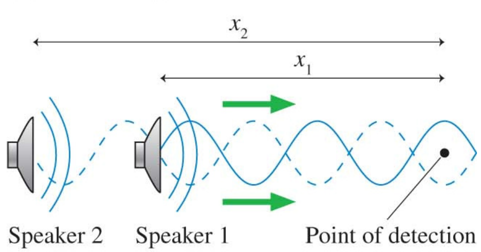
An open-closed tube has only *odd* harmonics. The next highest harmonic is $m = 3$, with frequency $f_3 = 3f_1 = 399$ Hz.

Interference in One Dimension

The pattern resulting from the superposition of two waves is often called interference. In this section we will look at the interference of two waves traveling in the *same* direction.

FIGURE 21.17 Two overlapped waves travel along the x-axis.

(**b**) Two overlapped sound waves



The Mathematics of Interference

As two waves of equal amplitude and frequency travel together along the x-axis, the net displacement of the medium is

$$D = D_1 + D_2 = a\sin(kx_1 - \omega t + \phi_{10}) + a\sin(kx_2 - \omega t + \phi_{20})$$
$$= a\sin\phi_1 + a\sin\phi_2$$

We can use a trigonometric identity to write the net displacement as

$$D = \left[2a\cos\frac{\Delta\phi}{2}\right]\sin(kx_{\text{avg}} - \omega t + (\phi_0)_{\text{avg}})$$

Where $\Delta\phi = \phi_2 - \phi_1$ is the phase difference between the two waves.

The Mathematics of Interference

The amplitude has a maximum value $A = 2a$ if $\cos(\Delta\phi/2) = \pm 1$. This occurs when

$$\Delta\phi = m \cdot 2\pi \qquad \text{(maximum amplitude } A = 2a\text{)}$$

Where m is an integer. Similarly, the amplitude is zero if $\cos(\Delta\phi/2) = 0$, which occurs when

$$\Delta\phi = \left(m + \frac{1}{2}\right) \cdot 2\pi \qquad \text{(minimum amplitude } A = 0\text{)}$$

EXAMPLE 21.10 Designing an antireflection coating

QUESTION:

EXAMPLE 21.10 Designing an antireflection coating

Magnesium fluoride (MgF_2) is used as an antireflection coating on lenses. The index of refraction of MgF_2 is 1.39. What is the thinnest film of MgF_2 that works as an antireflection coating at $\lambda = 510$ nm, near the center of the visible spectrum?

EXAMPLE 21.10 Designing an antireflection coating

MODEL Reflection is minimized if the two reflected waves interfere destructively.

EXAMPLE 21.10 Designing an antireflection coating

SOLVE The film thicknesses that cause destructive interference at wavelength λ are

$$d = \left(m - \frac{1}{2}\right)\frac{\lambda}{2n}$$

The thinnest film has $m = 1$. Its thickness is

$$d = \frac{\lambda}{4n} = \frac{510 \text{ nm}}{4(1.39)} = 92 \text{ nm}$$

The film thickness is significantly less than the wavelength of visible light!

EXAMPLE 21.10 Designing an antireflection coating

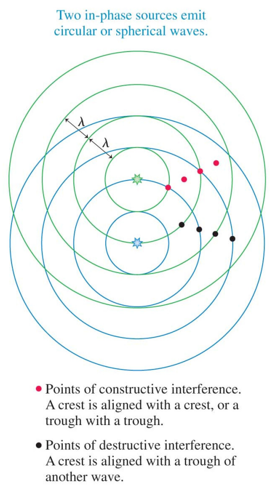
ASSESS The reflected light is completely eliminated (perfect destructive interference) only if the two reflected waves have equal amplitudes. In practice, they don't. Nonetheless, the reflection is reduced from $\approx 4\%$ of the incident intensity for "bare glass" to well under 1%. Furthermore, the intensity of reflected light is much reduced across most of the visible spectrum (400–700 nm), even though the phase difference deviates more and more from π rad as the wavelength moves away from 510 nm.

EXAMPLE 21.10 Designing an antireflection coating

It is the increasing reflection at the ends of the visible spectrum ($\lambda \approx 400$ nm and $\lambda \approx 700$ nm), where $\Delta\phi$ deviates significantly from π rad, that gives a reddish-purple tinge to the lenses on cameras and binoculars. Homework problems will let you explore situations where only one of the two reflections has a reflection phase shift of π rad.

Interference in Two and Three Dimensions

FIGURE 21.26 The overlapping ripple patterns of two sources. A few points of constructive and destructive interference are noted.



Interference in Two and Three Dimensions

The mathematical description of interference in two or three dimensions is very similar to that of one-dimensional interference. The conditions for constructive and destructive interference are

Maximum constructive interference:

$$\Delta\phi = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = m \cdot 2\pi$$

Perfect destructive interference:

$$\Delta\phi = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = \left(m + \frac{1}{2}\right) \cdot 2\pi$$

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

where Δr is the *path-length difference*.

Problem-Solving Strategy: Interference of two waves

PROBLEM-SOLVING STRATEGY 21.1 Interference of two waves

MODEL Make simplifying assumptions, such as assuming waves are circular and of equal amplitude.

Problem-Solving Strategy: Interference of two waves

VISUALIZE Draw a picture showing the sources of the waves and the point where the waves interfere. Give relevant dimensions. Identify the distances r_1 and r_2 from the sources to the point. Note any phase difference $\Delta\phi_0$ between the two sources.

Problem-Solving Strategy: Interference of two waves

SOLVE The interference depends on the path-length difference $\Delta r = r_2 - r_1$ and the source phase difference $\Delta\phi_0$.

$$\text{Constructive:} \quad \Delta\phi = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = m \cdot 2\pi$$

$$\text{Destructive:} \quad \Delta\phi = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = \left(m + \frac{1}{2}\right) \cdot 2\pi \qquad m = 0, 1, 2, \ldots$$

For identical sources ($\Delta\phi_0 = 0$), the interference is maximum constructive if $\Delta r = m\lambda$, perfect destructive if $\Delta r = \left(m + \frac{1}{2}\right)\lambda$.

Problem-Solving Strategy: Interference of two waves

ASSESS Check that your result has the correct units, is reasonable, and answers the question.

EXAMPLE 21.11 Two-dimensional interference between two loudspeakers

QUESTIONS:

EXAMPLE 21.11 Two-dimensional interference between two loudspeakers

Two loudspeakers in a plane are 2.0 m apart and in phase with each other. Both emit 700 Hz sound waves into a room where the speed of sound is 341 m/s. A listener stands 5.0 m in front of the loudspeakers and 2.0 m to one side of the center. Is the interference at this point maximum constructive, perfect destructive, or in between? How will the situation differ if the loudspeakers are out of phase?

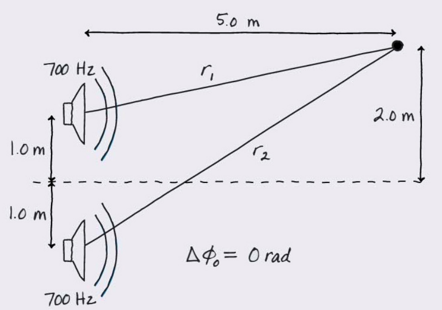
EXAMPLE 21.11 Two-dimensional interference between two loudspeakers

MODEL The two speakers are sources of in-phase, circular waves. The overlap of these waves causes interference.

EXAMPLE 21.11 Two-dimensional interference between two loudspeakers

VISUALIZE **FIGURE 21.29** shows the loudspeakers and defines the distances r_1 and r_2 to the point of observation. The figure includes dimensions and notes that $\Delta\phi_0 = 0$ rad.

FIGURE 21.29 Pictorial representation of the interference between two loudspeakers.



EXAMPLE 21.11 Two-dimensional interference between two loudspeakers

SOLVE It's not r_1 and r_2 that matter, but the *difference* Δr between them. From the geometry of the figure we can calculate that

$$r_1 = \sqrt{(5.0\ \text{m})^2 + (1.0\ \text{m})^2} = 5.10\ \text{m}$$

$$r_2 = \sqrt{(5.0\ \text{m})^2 + (3.0\ \text{m})^2} = 5.83\ \text{m}$$

Thus the path-length difference is $\Delta r = r_2 - r_1 = 0.73$ m. The wavelength of the sound waves is

$$\lambda = \frac{v}{f} = \frac{341\ \text{m/s}}{700\ \text{Hz}} = 0.487\ \text{m}$$

EXAMPLE 21.11 Two-dimensional interference between two loudspeakers

In terms of wavelengths, the path-length difference is $\Delta r/\lambda = 1.50$, or

$$\Delta r = \frac{3}{2}\lambda$$

Because the sources are in phase ($\Delta\phi_0 = 0$), this is the condition for *destructive* interference. If the sources were out of phase ($\Delta\phi_0 = \pi$ rad), then the phase difference of the waves at the listener would be

$$\Delta\phi = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = 2\pi\left(\frac{3}{2}\right) + \pi \text{ rad} = 4\pi \text{ rad}$$

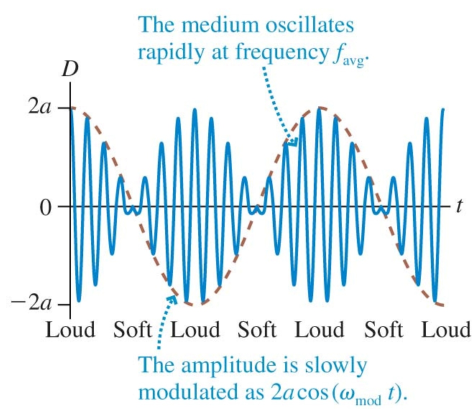
This is an integer multiple of 2π rad, so in this case the interference would be *constructive*.

EXAMPLE 21.11 Two-dimensional interference between two loudspeakers

ASSESS Both the path-length difference *and* any inherent phase difference of the sources must be considered when evaluating interference.

Beats

FIGURE 21.32 Beats are caused by the superposition of two waves of nearly identical frequency.



Beats

- With beats, the sound intensity rises and falls *twice* during one cycle of the modulation envelope.
- Each "loud-soft-loud" is one beat, so the **beat frequency** f_{beat}, which is the number of beats per second, is *twice* the modulation frequency f_{mod}.
- The beat frequency is

$$f_{beat} = 2f_{mod} = 2\frac{\omega_{mod}}{2\pi} = 2\cdot\frac{1}{2}\left(\frac{\omega_1}{2\pi} - \frac{\omega_2}{2\pi}\right) = f_1 - f_2$$

where, to keep f_{beat} from being negative, we will always let f_1 be the larger of the two frequencies. The beat is simply the *difference* between the two individual frequencies.

EXAMPLE 21.13 Listening to beats

QUESTIONS:

EXAMPLE 21.13 Listening to beats
One flutist plays a note of 510 Hz while a second plays a note of 512 Hz. What frequency do you hear? What is the beat frequency?

EXAMPLE 21.13 Listening to beats

SOLVE You hear a note with frequency $f_{avg} = 511$ Hz. The beat frequency is

$$f_{beat} = f_1 - f_2 = 2 \text{ Hz}$$

You (and they) would hear two beats per second.

EXAMPLE 21.13 Listening to beats

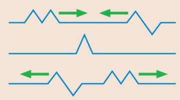
ASSESS If a 510 Hz note and a 512 Hz note were played separately, you would not be able to perceive the slight difference in frequency. But when the two notes are played together, the obvious beats tell you that the frequencies are slightly different. Musicians learn to make constant minor adjustments in their tuning as they play in order to eliminate beats between themselves and other players.

Chapter 21. Summary Slides

General Principles

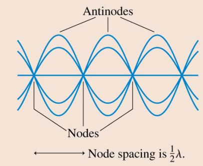
Principle of Superposition

The displacement of a medium when more than one wave is present is the sum of the displacements due to each individual wave.



Important Concepts

Standing waves are due to the superposition of two traveling waves moving in opposite directions.

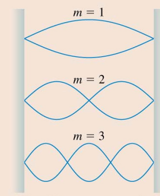


The amplitude at position x is

$$A(x) = 2a \sin kx$$

where a is the amplitude of each wave.

The boundary conditions determine which standing-wave frequencies and wavelengths are allowed. The allowed standing waves are **modes** of the system.



Standing waves on a string

Important Concepts

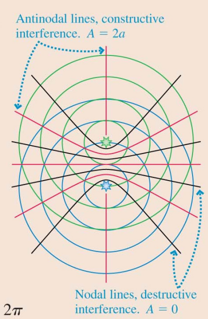
Interference

In general, the superposition of two or more waves into a single wave is called interference.

Maximum constructive interference occurs where crests are aligned with crests and troughs with troughs. These waves are in phase. The maximum displacement is $A = 2a$.

Perfect destructive interference occurs where crests are aligned with troughs. These waves are out of phase. The amplitude is $A = 0$.

Interference depends on the phase difference $\Delta\phi$ between the two waves.



Constructive: $\Delta\phi = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = m \cdot 2\pi$

Destructive: $\Delta\phi = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = \left(m + \frac{1}{2}\right) \cdot 2\pi$

Δr is the path-length difference of the two waves, and $\Delta\phi_0$ is any phase difference between the sources. For identical sources (in phase, $\Delta\phi_0 = 0$):

Interference is constructive if the path-length difference $\Delta r = m\lambda$.

Interference is destructive if the path-length difference $\Delta r = \left(m + \frac{1}{2}\right)\lambda$.

The amplitude at a point where the phase difference is $\Delta\phi$ is $A = \left|2a\cos\left(\frac{\Delta\phi}{2}\right)\right|$.

Applications

Boundary conditions

Strings, electromagnetic waves, and sound waves in closed-closed tubes must have nodes at both ends:

$$\lambda_m = \frac{2L}{m} \qquad f_m = m\frac{v}{2L} = mf_1$$

where $m = 1, 2, 3, \ldots$.

The frequencies and wavelengths are the same for a sound wave in an open-open tube, which has antinodes at both ends.

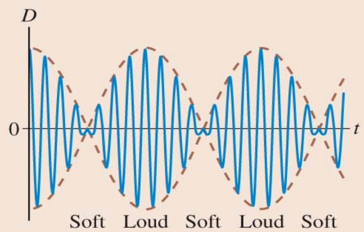
A sound wave in an open-closed tube must have a node at the closed end but an antinode at the open end. This leads to

$$\lambda_m = \frac{4L}{m} \qquad f_m = m\frac{v}{4L} = mf_1$$

where $m = 1, 3, 5, 7, \ldots$.

Applications

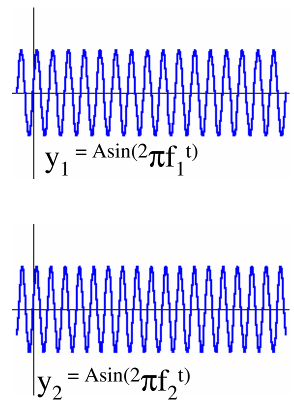
Beats (loud-soft-loud-soft modulations of intensity) occur when two waves of slightly different frequency are superimposed.

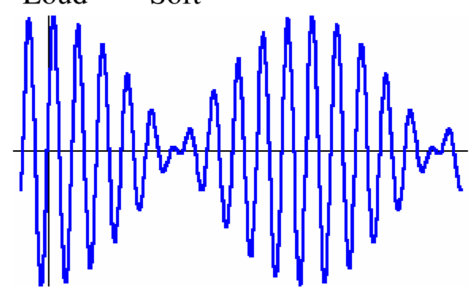


The beat frequency between waves of frequencies f_1 and f_2 is

$$f_{beat} = f_1 - f_2$$

- Beat occurs due to the superposition of two waves of different f and same A

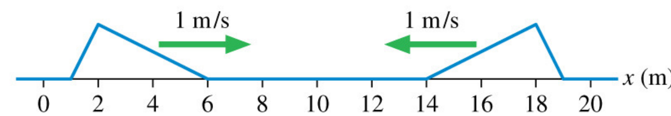




$$y = y_1 + y_2 = \left[2A\cos 2\pi\left(\frac{f_1 - f_2}{2}\right)t\right]\cos 2\pi\left(\frac{f_1 + f_2}{2}\right)t$$

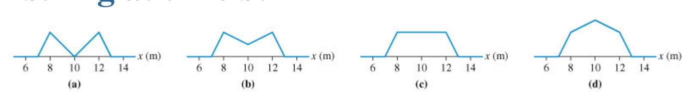
$$f_{beat} = |f_2 - f_1|$$

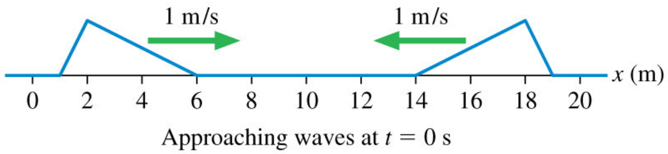
Chapter 21. Clicker Questions



Approaching waves at $t = 0$ s

Two pulses on a string approach each other at speeds of 1 m/s. What is the shape of the string at t = 6 s?





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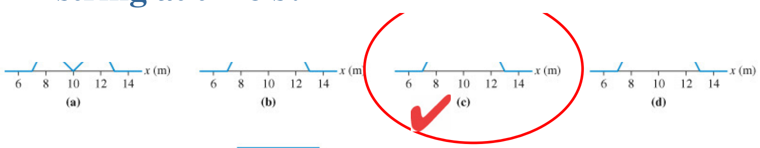
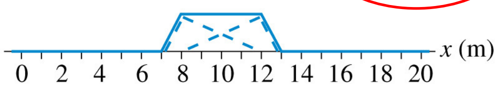
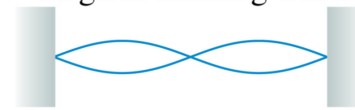
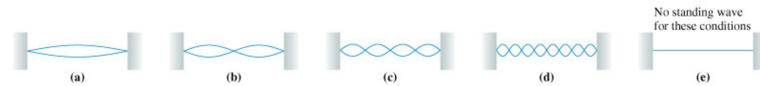




Original standing wave



A standing wave on a string vibrates as shown at the top. Suppose the tension is quadrupled while the frequency and the length of the string are held constant. Which standing wave pattern is produced?



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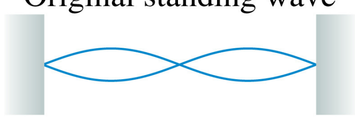

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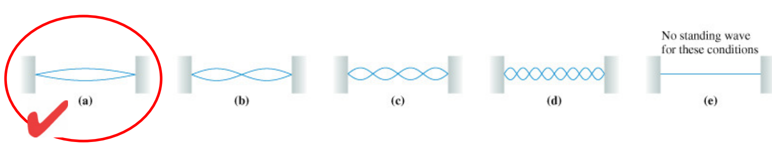

An open-open tube of air supports standing waves at frequencies of 300 Hz and 400 Hz, and at no frequencies between these two. The second harmonic of this tube has frequency

A. 800 Hz.

B. 200 Hz.

C. 600 Hz.

D. 400 Hz.

E. 100 Hz.

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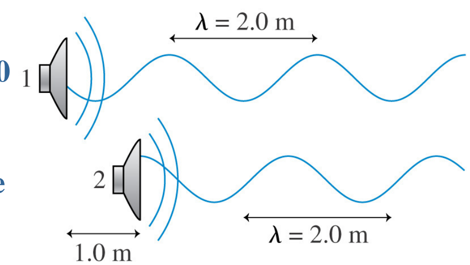
Two loudspeakers emit waves with λ = 2.0 m. Speaker 2 is 1.0 m in front of speaker 1. What, if anything, must be done to cause constructive interference between the two waves?



A. Move speaker 1 forward (to the right) 0.5 m.
B. Move speaker 1 backward (to the left) 1.0 m.
C. Move speaker 1 forward (to the right) 1.0 m.
D. Move speaker 1 backward (to the left) 0.5 m.
E. Nothing. The situation shown already causes constructive interference.

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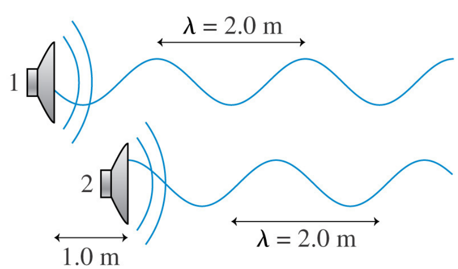

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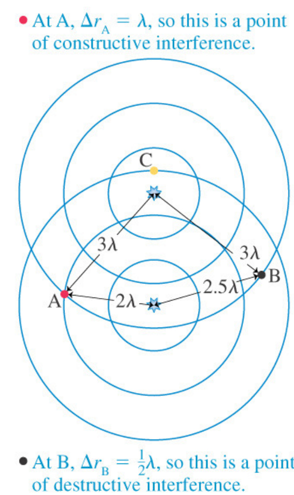
E. Nothing. The situation shown already causes constructive interference.

The interference at point C in the figure at the right is



A. maximum constructive.
B. destructive, but not perfect.
C. constructive, but less than maximum.
D. perfect destructive.
E. there is no interference at point C.

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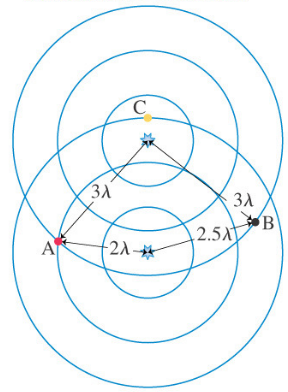

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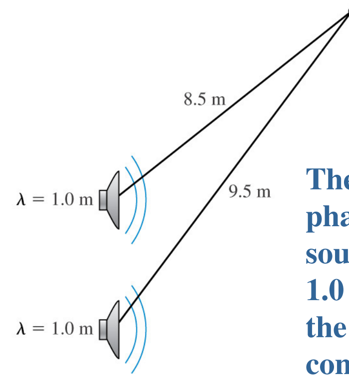
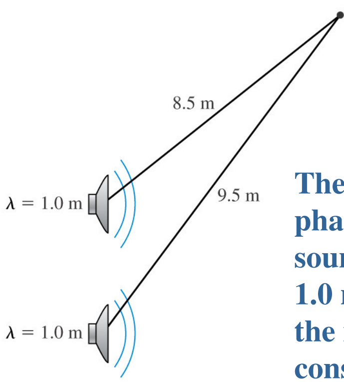


These two loudspeakers are in phase. They emit equal-amplitude sound waves with a wavelength of 1.0 m. At the point indicated, is the interference maximum constructive, perfect destructive or something in between?

A. perfect destructive
B. maximum constructive
C. something in between



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A. perfect destructive
B. maximum constructive
C. something in between

You hear three beats per second when two sound tones are generated. The frequency of one tone is known to be 610 Hz. The frequency of the other is

A. 604 Hz.
B. 607 Hz.
C. 613 Hz.
D. 616 Hz.
E. Either b or c.

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