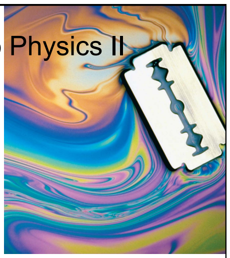
PHY132H1F Introduction to Physics II
Class 3 – **Outline:**

- Doppler Effect
- Principle of Superposition
- Standing Waves on a String
- Standing Sound Waves
- Wave Interference
- Beats



Survey: How did the reading go that I assigned? (please be honest – this is just a survey)

A. I read all of Knight Chapter 21, fairly thoroughly.
B. I read all of Knight Chapter 21, but I was mostly "skimming".
C. I read most of Knight Chapter 21 (more than half of it).
D. I read some of Knight Chapter 21 (less than half of it).
E. I did not do the assigned reading.

Quick reading quiz..

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

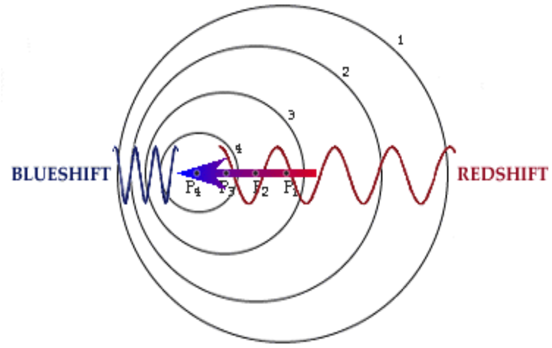
A. Harmonics
B. Normal Modes
C. Nodes
D. Anti-nodes
E. Interference

Quick reading quiz…

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.

Doppler Effect



The Doppler Effect

The frequencies heard by a stationary observer when the sound source is moving at speed v_0 are

$$f_+ = \frac{f_0}{1 - v_s/v} \quad \text{(Doppler effect for an approaching source)}$$

$$f_- = \frac{f_0}{1 + v_s/v} \quad \text{(Doppler effect for a receding source)}$$

The frequencies heard by an observer moving at speed v_0 relative to a stationary sound source emitting frequency f_0 are

$$f_+ = (1 + v_o/v)f_0 \quad \text{(observer approaching a source)}$$

$$f_- = (1 - v_o/v)f_0 \quad \text{(observer receding from a source)}$$

Which statement is true?

Valerie is standing in the middle of the road, as a police car approaches her at a constant speed, v. The siren on the police car emits a “rest frequency” of f_0.

A. The frequency she hears rises steadily as the police car gets closer and closer.
B. The frequency she hears steadily decreases as the police car gets closer and closer.
C. The frequency she hears does not change as the police car gets closer.

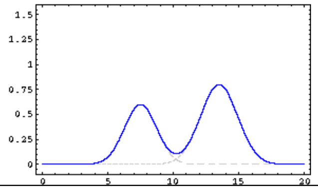
Which statement is true?

Valerie is standing still as a police car approaches her at a constant speed, v. Daniel is in his car moving at the same constant speed, v, toward an identical police car which is standing still. Both hear a siren.

A. The frequency Daniel hears is lower than the frequency Valerie hears.
B. The frequency Daniel hears is higher than the frequency Valerie hears.
C. The frequencies that Daniel and Valerie hear are exactly the same.

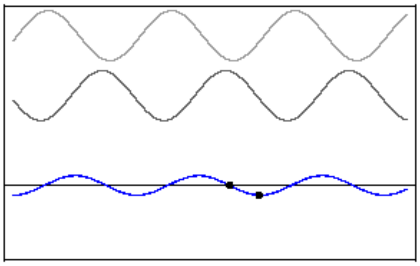
Chapter 21: Principle of Superposition

- If two or more waves combine at a given point, the resulting disturbance is the *sum* of the disturbances of the individual waves.
- Two traveling waves can pass through each other without being destroyed or even altered!

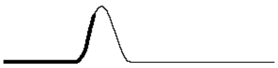


Standing Wave:

The superposition of two 1-D sinusoidal waves traveling in opposite directions.

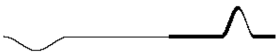


Reflection of Transverse Wave Pulse



- A pulse traveling to the right on a heavy string attached to a lighter string
- Speed suddenly increases

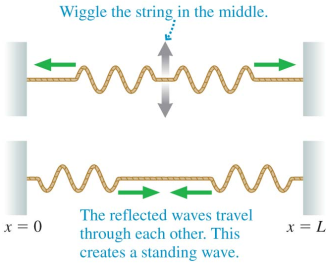
Reflection of Transverse Wave Pulse



- A pulse traveling to the right on a light string attached to a heavier string
- Speed suddenly decreases

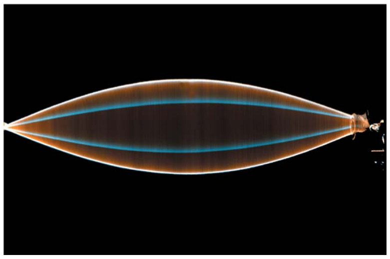
Standing Waves on a String

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



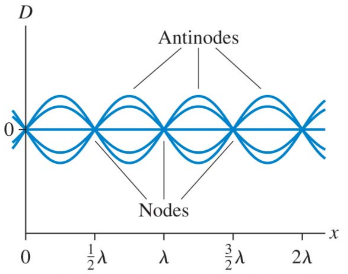
Standing Waves

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



Which mode is this?

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



The nodes and antinodes are spaced $\lambda/2$ apart.

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

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

Because $\lambda f = v$ for a sinusoidal wave, the oscillation frequency corresponding to wavelength λ_m is

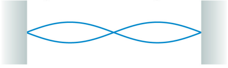
$$f_m = \frac{v}{\lambda_m} = \frac{v}{2L/m} = m\frac{v}{2L} \qquad m = 1, 2, 3, 4, \ldots$$

Standing Waves on a String

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

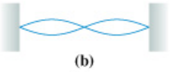
1. *m* is the number of *antinodes* on the standing wave, not the number of nodes. You can tell a string's mode of oscillation by counting the number of antinodes.
2. The *fundamental mode*, with $m = 1$, has $\lambda_1 = 2L$, not $\lambda_1 = L$. Only half of a wavelength is contained between the boundaries, 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, $f_1 = \Delta f = f_{m+1} - f_m$.

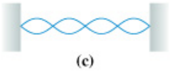
Original standing wave

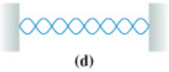


A standing wave on a string vibrates as shown at the top. Suppose the frequency is doubled while the tension and the length of the string are held constant. Which standing wave pattern is produced?

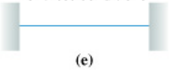

(a)


(b)

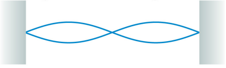

(c)


(d)

No standing wave for these conditions


(e)

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?

(a)

(b)

(c)

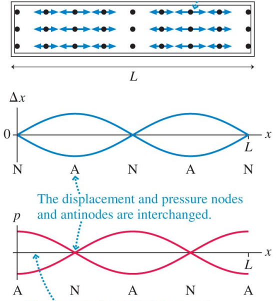
(d)

No standing wave
for these conditions

(e)

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.



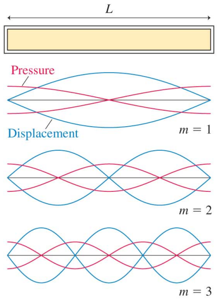
The closed end is a displacement node and a pressure antinode.

Air molecules undergo longitudinal oscillations. This is a displacement antinode and a pressure node.

The displacement and pressure nodes and antinodes are interchanged.

The pressure is oscillating around atmospheric pressure p_{atmos}.

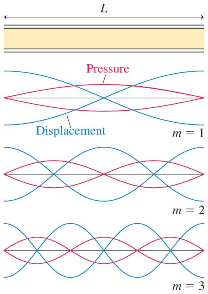
(a) Closed-closed



$$\left\{\begin{aligned}\lambda_m &= \frac{2L}{m}\\ f_m &= m\frac{v}{2L} = mf_1\end{aligned}\right.$$

$m = 1, 2, 3, 4, \ldots$
(open-open or closed-closed tube)

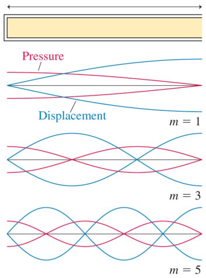
(b) Open-open



$$\left\{\begin{aligned}\lambda_m &= \frac{2L}{m}\\ f_m &= m\frac{v}{2L} = mf_1\end{aligned}\right.$$

$m = 1, 2, 3, 4, \ldots$
(open-open or closed-closed tube)

(c) Open-closed



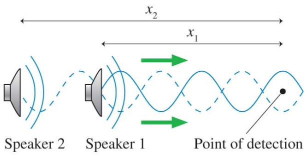
$$\left\{\begin{aligned}\lambda_m &= \frac{4L}{m}\\ f_m &= m\frac{v}{4L} = mf_1\end{aligned}\right.$$

$m = 1, 3, 5, 7, \ldots$
(open-closed tube)

Wave Interference

- The pattern resulting from the superposition of two waves is often called interference. Interference can be
- ***constructive***, meaning the disturbances **add** to make a resultant wave of **larger** amplitude, or
- ***destructive***, meaning the disturbances **cancel**, making a resultant wave of **smaller** amplitude.

(b) Two overlapped sound waves



Before Next Class:

- Try the Suggested End Of Chapter Problems that I assigned from Chapter 21 (they are posted under "Materials" on the course web site).

- Read the first four sections of Chapter 23 on Ray Optics, Reflection and Refraction.

See you Wednesday!