## Section 9.3 - Beats (or bad tuning)

An acoustical beat is a periodic change in sound intensity caused by the interference between two nearly identical sound waves.

Acoustical beats are formed when the frequencies of interfering waves are very close in value. You hear beats as a change in loudness, from soft to loud.

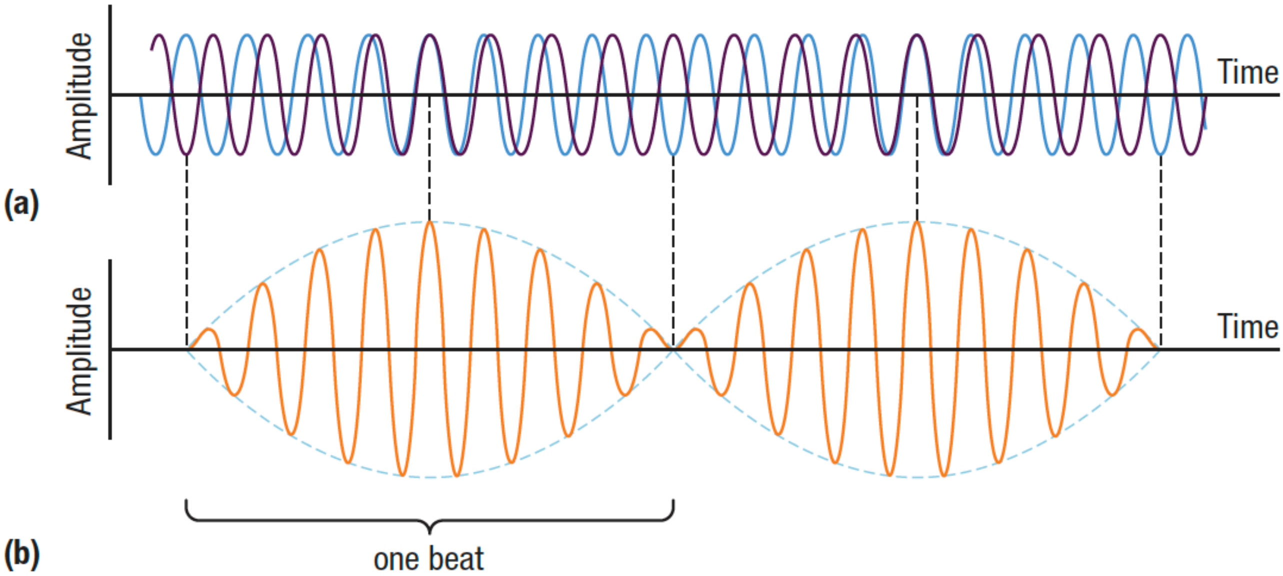


**Figure 1** Beats are formed by the superposition of two waves with slightly different frequencies. (a) The individual sound waves are heard by an observer at some location within the medium. (b) The combined wave has an amplitude (blue dashed line) that varies in a regular manner.

## Drone Demo or Tuning Forks

The beat frequency is the frequency of the beats produced by the interference of two waves with slightly different frequencies. It is equal to the difference in frequencies of the two interfering waves.

## 9.3 Summary

- Acoustical beats are an interference pattern formed by two waves with nearly identical frequencies.
- You can hear an acoustical beat as a periodic change in sound intensity.
- Many musical instruments can be tuned by a musician or an instrument tuner by listening to the beats generated between a standard note and that of their instrument.

## 9.3 Questions

1. Explain how beats are created. Refer to the principle of superposition. K/U
2. You are tuning a guitar by comparing the sound produced by the string with the sound produced by a standard tuning fork. You notice a beat frequency of 5 Hz when both sounds are present. As you tighten the guitar string, the beat frequency rises steadily to 8 Hz. In order to tune the string exactly to the tuning fork, should you continue to tighten the string or loosen the string? Explain your answer. K/U C
3. An airplane mechanic notices that the sound from an aircraft with two engines varies rapidly in loudness when both engines are running. What could be causing this variation from loud to soft? K/U
4. The two waveforms in **Figure 5** have the same amplitude but different frequencies. They are interfering with each other. Copy the two waveforms into your notebook, and draw the resulting beat pattern. Mark the points of constructive interference and destructive interference. K/U T/I C

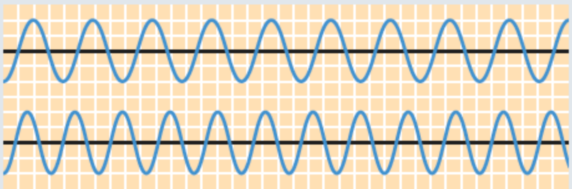

**Figure 5**

Section 9.3 #1, 2

# Section 9.4 - Damping and Resonance

**<u>damping</u>** a reduction in the amplitude of a wave as a result of energy absorption or destructive interference

Child being pushed consistently on a swing

Child on a swing AFTER pushing stops

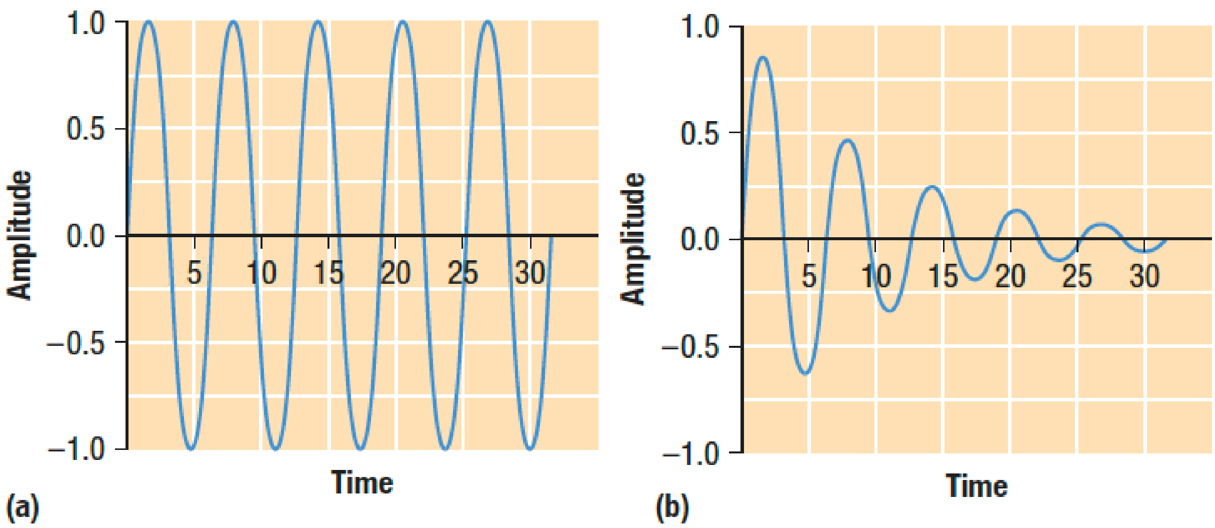


**Figure 1** (a) Notice the consistent amplitude—this waveform is not being damped. (b) Notice how the amplitude decreases over time—this waveform is being damped. The amplitude will never increase unless energy is added to replace the energy that has been absorbed by the medium.

# Resonance

**resonant frequency** the frequency at which a medium vibrates most easily

**resonance** the condition in which the frequency of a wave equals the resonant frequency of the wave's medium

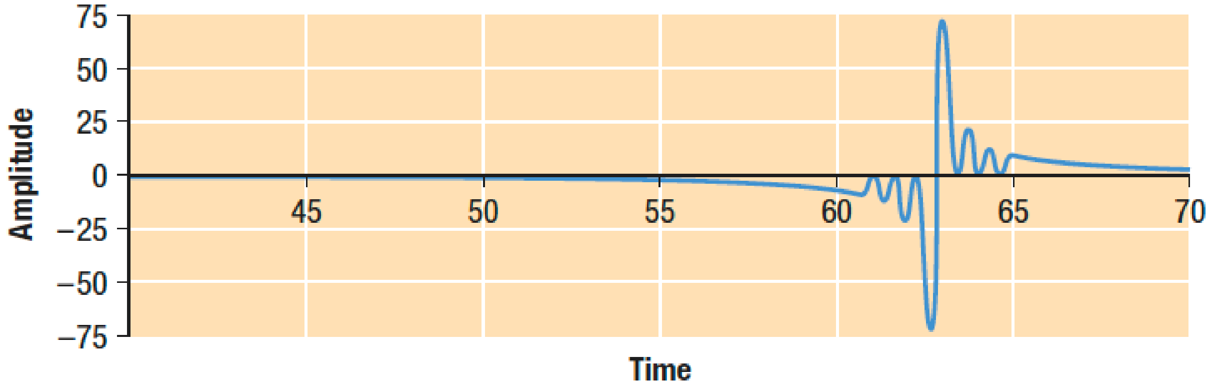


**Figure 2** This waveform was generated by the interference of 100 waveforms. Over most of the graph the amplitude is so small that you cannot see it. However, when a resonant frequency is reached, the amplitude increases dramatically due to interference. Little energy is lost. Therefore, when the resonant conditions are met, significantly higher amplitudes are achieved. By adding 100 waves of frequencies that are fairly close, the waves combine to form a peak using constructive interference.

# Resonance and Standing Waves

Recall from Section 9.2 that for a standing wave to occur, the wavelength (and frequency) of a wave must be a multiple of one of the harmonics. If the frequency of the wave is not a multiple of one of the harmonics, a pattern will appear that no longer has nodes, and the visible "standing" effect is lost, as shown in **Figure 3**. We often will see this as a reduction in amplitude. The real effect comes from losing the nodes so that the string shown in Figure 3 vibrates in changing locations, making it difficult to see.

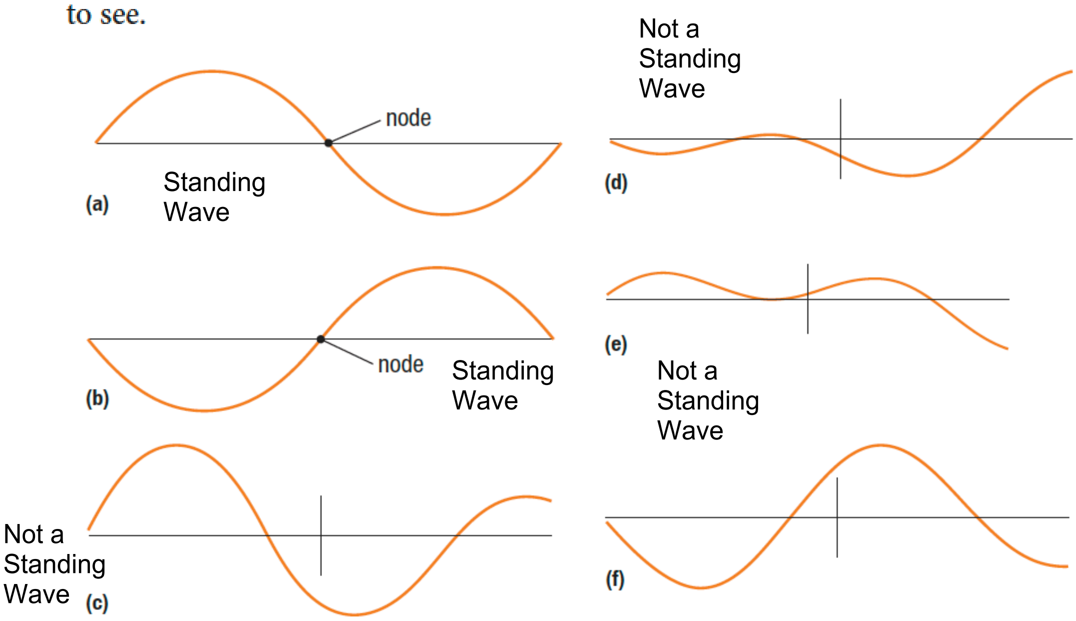


**Figure 3** Parts (a) and (b) illustrate a typical $n = 2$ standing wave. Parts (c) to (f) illustrate the chaotic patterns that occur if the frequency is not at the correct value to set up a standing wave. Notice that in (a) and (b) the node shows no movement. In parts (c) through (f) there is no node.

Breaking Glass with Resonance

## Damping and Resonance in Vibrating Structures

Damping is sometimes desirable. You may want to reduce the effects of a vibration, so that sound will not carry from one room to the next, for example, or in a complicated structure such as a car or a building, where the effects of strong vibration can be dangerous.

In complicated structures such as a building, each component has its own resonant frequency and harmonics. When an external force, such as the wind, vibrates such a system at a frequency close to the structure's resonant frequency, then resonance occurs. The amplitude of the vibration in the system increases significantly, perhaps to the point of damaging the building. For this reason, engineers are careful to avoid situations where resonance might occur within structures. They must carefully analyze structures to determine their resonant frequencies. While a building may not fall down as a result of such vibrations, other effects such as metal fatigue can occur that can damage the structure. Much experimentation is required to determine resonant frequencies of an entire structure. This phenomenon is called mechanical resonance and is described in more detail in Chapter 10.

Earthquake shake test - model

Comparative earthquake engineering experiments with 12-story building models: the right one is resting on a new type of seismic base isolation called "earthquake protectors", the left one is fixed to the base. The fundamental natural period of superstructures equals 1.2s, the isolated period of Earthquake Protector equals 5.0s, the range of earthquake simulation periods is 0.02 - 2.00s. It is obvious: application of Earthquake Protector can raise a building's seismic sustainability dramatically.

Shake table video

Complete the table below based on the above video - describe the movement as: none, some, max

Movement Description

| Time | Frequency | Short | Medium | Tall |
|---|---|---|---|---|
| 1:14 mark | | | | |
| 1:55 mark | | | | |
| 3:24 mark | | | | |

This shows the effect of hitting a resonant frequency on a model.

It also shows how the model's shape affects the resonant frequency.

You can transfer this idea to earthquake engineering. If an earthquake shakes the ground at certain frequency, only certain buildings will be affected, not always the tallest, while others will be unaffected.

Tacoma Narrows - remember this is a STEEL Bridge

Looks Like Resonance but...

Tacoma Narrows Flutter

rice on table video

Turn down the volume a bit first. Rice spread over a plate, on top of a speaker (or vibrating source). The rice will migrate to very specific locations. Why might that be?

## 9.4 Summary

- Damping is a condition in which the amplitude of a wave is reduced. Either the medium removes energy from a wave, or the effects of destructive interference reduce its amplitude.
- Damping due to destructive interference results in little energy loss. Given the right conditions, the amplitude can rapidly increase.
- All materials have frequencies at which they vibrate most easily, called the resonant frequency.
- Resonance is the condition in which the frequency of a system equals the wave medium's resonant frequency or one of its harmonics. The wave's amplitude can increase.
- Resonance is avoided in situations such as building construction where vibrations with large amplitudes are undesirable.

## 9.4 Questions

1. Define the following terms in your own words: K/U C
   (a) damping
   (b) resonant frequency
   (c) resonance
2. (a) Identify the two causes of damping.
   (b) Explain how damping occurs. K/U
3. If a mass–spring system is hung vertically and set into vibration, why does the motion eventually stop? K/U
4. All automobiles have shock absorbers. Research shock absorbers, and explain why they are used and how they work. C A
5. Explain how standing waves are an example of resonance. K/U
6. Either through research or from your experience, identify two examples of damping that were not mentioned in this section. Explain why you think they are examples of damping. K/U A
7. Either through research or from your own experience, identify two situations of resonance of a mechanical system (that is, no light, electronics, or magnetism). K/U A
   (a) How do you know they are examples of resonance?
   (b) There will be a source of damping in each situation. Identify that source in each situation.
8. (a) Does resonance only occur when the amplitude is as high as can possibly be?
   (b) Given your answer in (a), would you expect more than one resonant frequency in a given situation? Explain. K/U A

GO TO NELSON SCIENCE

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