9.4 Damping and Resonance

If you push a child on a swing once, the child and swing will move back and forth. However, they will not move indefinitely. Eventually, the movement will slow down, and the child–swing system will come to rest at its equilibrium position. Friction between the child–swing system and air resistance reduce the energy in the child–swing system as time passes. The swing motion is said to be affected by **damping**. The air and the child–swing system absorb the energy provided by the push on the swing. We can observe absorption of wave energy by a medium as a reduction in the amplitude of the wave. **Figure 1** compares a waveform that has not been damped (Figure 1(a)) with a waveform that has been damped (Figure 1(b)). Destructive interference from many superimposed waveforms can also result in a reduction in the wave amplitude.

damping a reduction in the amplitude of a wave as a result of energy absorption or destructive interference

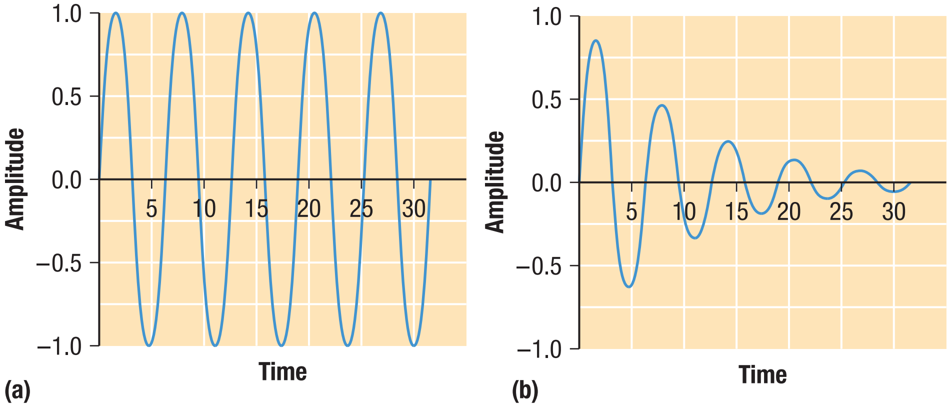

Figure 1 (a) Notice the consistent amplitude—this waveform is not being damped. (b) Notice how the amplitude decreases over time—this waveform is being damped. The amplitude will never increase unless energy is added to replace the energy that has been absorbed by the medium.

Resonance

All materials have frequencies at which they vibrate most easily. This is known as the system's **resonant frequency**. Consider the child–swing example. Suppose you keep the swing in motion by continuously pushing it with a certain frequency. To increase the amplitude of the swing motion, you must push the swing each time it returns to your hands. The amplitude can reach a maximum when the frequency of the pushing equals the natural frequency of the swing system, or the resonant frequency. Under these conditions, the child–swing system is said to be in **resonance**. If the energy put into the child–swing system per cycle of motion equals the energy lost as a result of friction, the amplitude remains constant. In other words, the damping effects are significantly reduced so that the amplitude can increase. An example of the dramatic increase in amplitude that can occur due to resonance is shown in **Figure 2**.

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

WEB **LINK**

To see a video demonstrating resonance,

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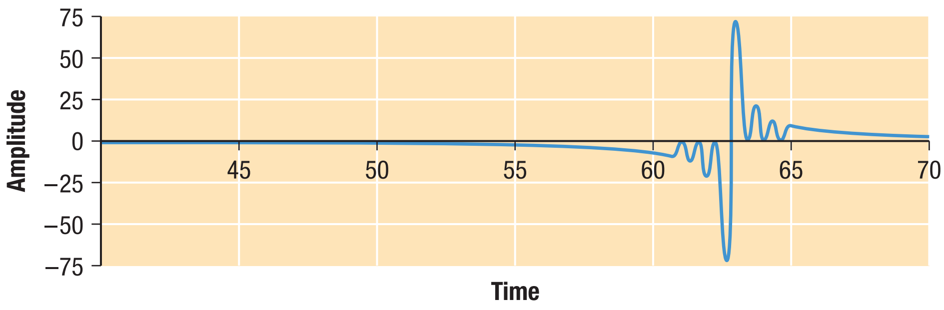

Figure 2 This waveform was generated by the interference of 100 waveforms. Over most of the graph the amplitude is so small that you cannot see it. However, when a resonant frequency is reached, the amplitude increases dramatically due to interference. Little energy is lost. Therefore, when the resonant 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.

Investigation 9.4.1

Investigating Standing Waves in an Air Column (p. 439)

In this investigation, you will investigate standing waves as generated in an air column and find points of resonance.

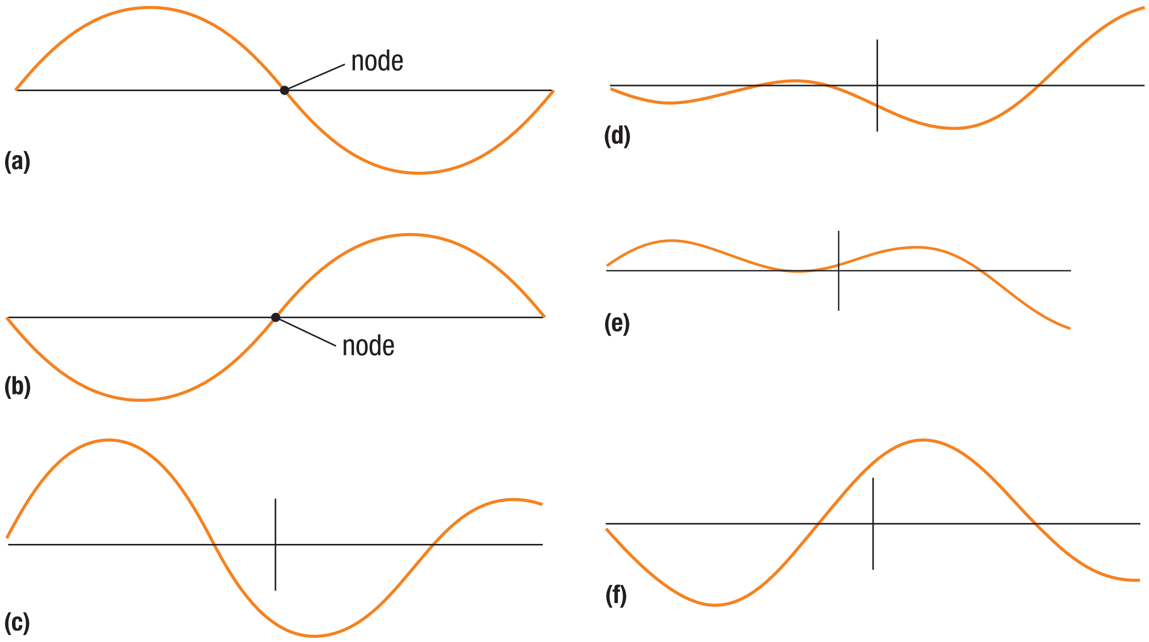

Figure 3 Parts (a) and (b) illustrate a typical $n = 2$ standing wave. Parts (c) to (f) illustrate the chaotic patterns that occur if the frequency is not at the correct value to set up a standing wave. Notice that in (a) and (b) the node shows no movement. In parts (c) through (f) there is no node.

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.

CAREER **LINK**

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UNIT TASK **BOOKMARK**

As you work on the Unit Task on page 486, apply what you have learned about resonance to music and to structures and buildings.

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

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