

March 4: More on Waves

Objectives

- Evaluate combinations of waves in confined systems.
- Explain the refraction of waves.
- Explain the behavior of ocean waves near the shore.

What's the point?

- How is energy carried by waves?
- How do waves behave?

Addition of waves

Waves combine by adding together. The general term for the addition of two waves is **interference**. Interference is **constructive** when the resulting wave has an amplitude higher than either of the combining waves, and **destructive** when the resulting wave has a lower amplitude.

Beats

Waves with slightly different frequencies interfere to form a wave whose amplitude changes periodically. The cyclic variations are known as **beats**. The beat frequency is the difference between the frequencies of the component waves.

Standing Waves

Waves with identical frequencies moving in opposite directions combine to form a **standing wave** whose velocity is zero, but whose amplitude cycles with the same frequency as the component waves. A standing wave displays **nodes**, where the amplitude is always zero, and **antinodes**, where the amplitude changes maximally.

Resonance

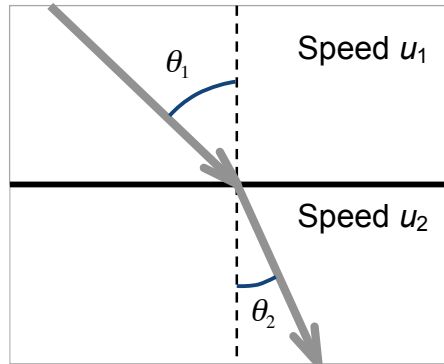
Objects vibrate with characteristic frequencies. The lowest mode of vibration is the **fundamental**, and higher modes are **harmonics**. Frequencies of harmonics are whole-number multiples of the fundamental frequency.

The tones of musical instruments are determined by differing energies of harmonics in the sounds they produce.

Refraction

Waves may have different speeds in different media. When waves move into a medium that causes them to change speed, they may also change direction, as given by **Snell's law**:

$$u_2 \sin \theta_1 = u_1 \sin \theta_2$$



Here, the directions of the waves are shown by **rays**, which point in the direction of the velocity of the waves. The angle between the **incident** wave and the interface is θ_1 ; the angle between the **transmitted** wave and the interface is θ_2 .

Water waves

Water waves are slower in shallow water than in deep water. This causes them to bend toward beaches. It also causes the wavelengths to decrease as they come to shore, so the amplitudes correspondingly increase. The waves break when the deep crests outrun the shallow troughs.