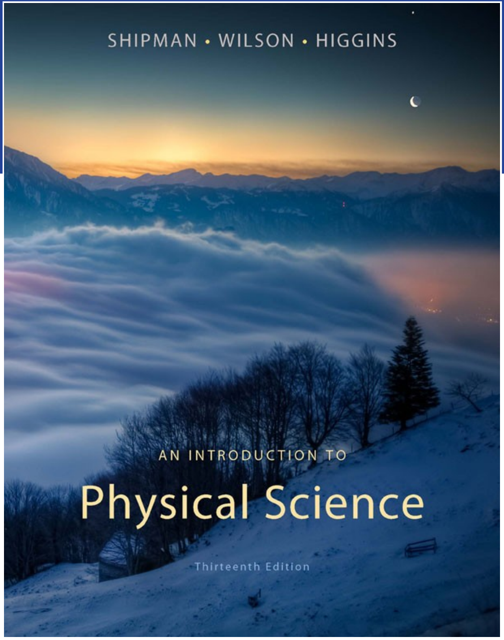

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CENGAGE Learning™

James T. Shipman
Jerry D. Wilson
Charles A. Higgins, Jr.

Chapter 6

Waves and Sound

Waves

- We know that when matter is disturbed, energy emanates from the disturbance. This propagation of energy from the disturbance is know as a wave.
  - We call this transfer of energy wave motion.
- Examples include ocean waves, sound waves, electromagnetic waves, and seismic (earthquake) waves.

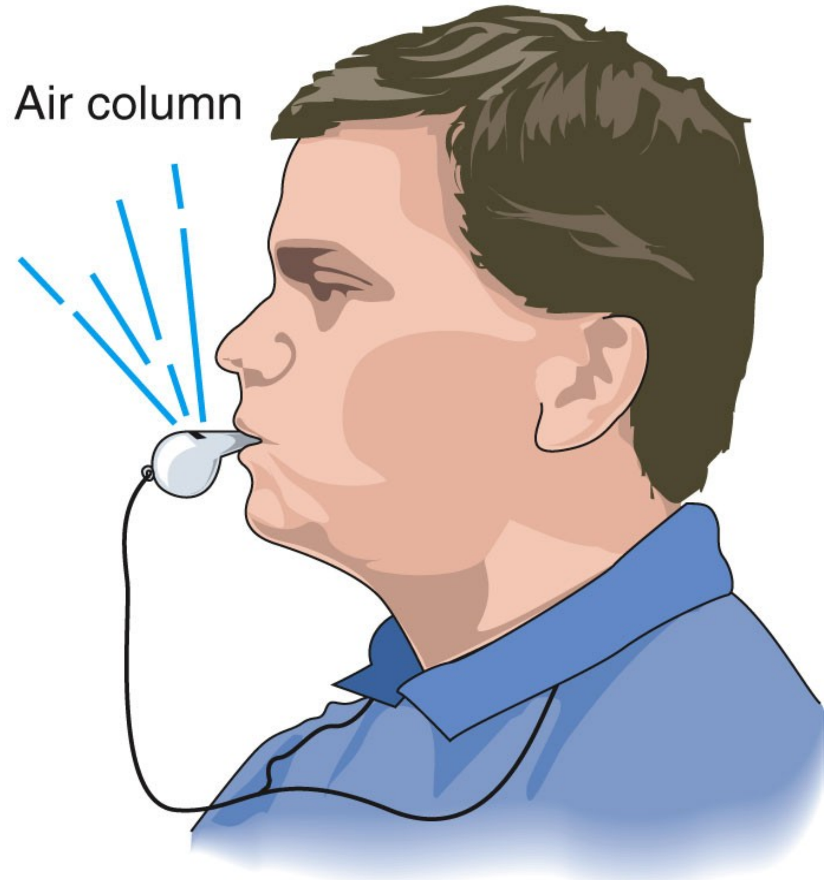
Audio Link

Wave Motion

- Waves transfer energy and generally not matter through a variety of mediums.
  - The wave form is in motion but not the matter.
- Water waves (liquid) essentially bob you up and down but not sideways.
- Earthquakes waves move through the Earth. (solid)
- Sound waves travel through the air. (gas)
- Electromagnetic radiation waves travel through space. (void)

Wave Properties

- A disturbance may be a single pulse or shock (hammer), or it may be periodic (guitar string).

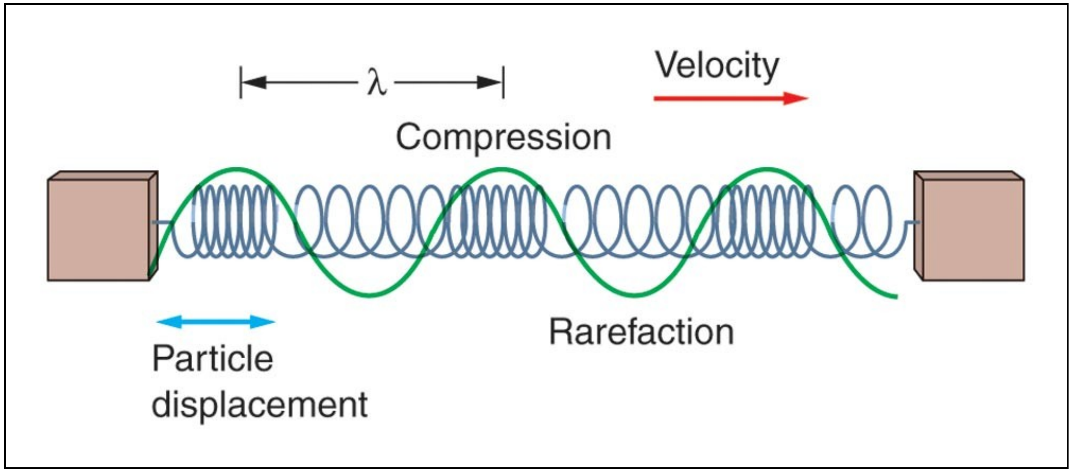


Longitudinal and Transverse Waves

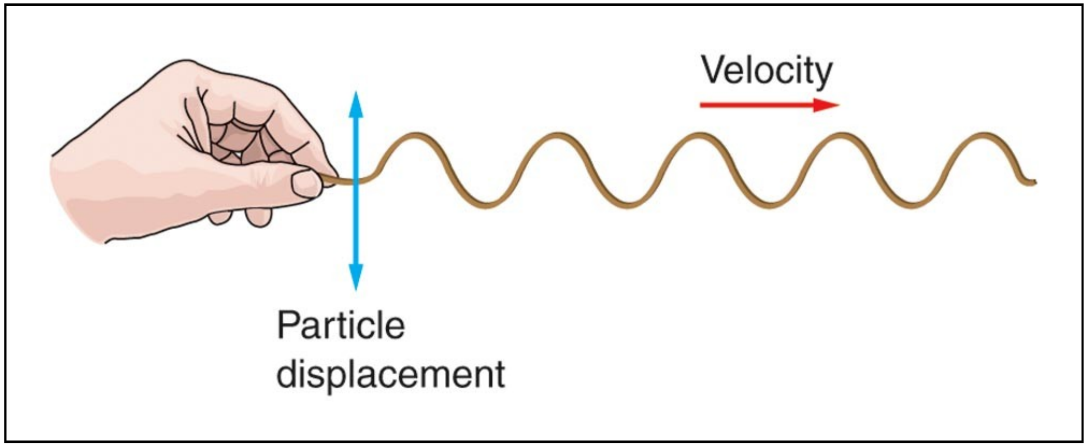
- Two types of waves classified on their particle motion and wave direction:
- Longitudinal – particle motion and the wave velocity are parallel to each other
  - Sound is a longitudinal wave.
- Transverse – particle motion is perpendicular to the direction of the wave velocity
  - Light is an example of a transverse wave.

Longitudinal & Transverse Waves

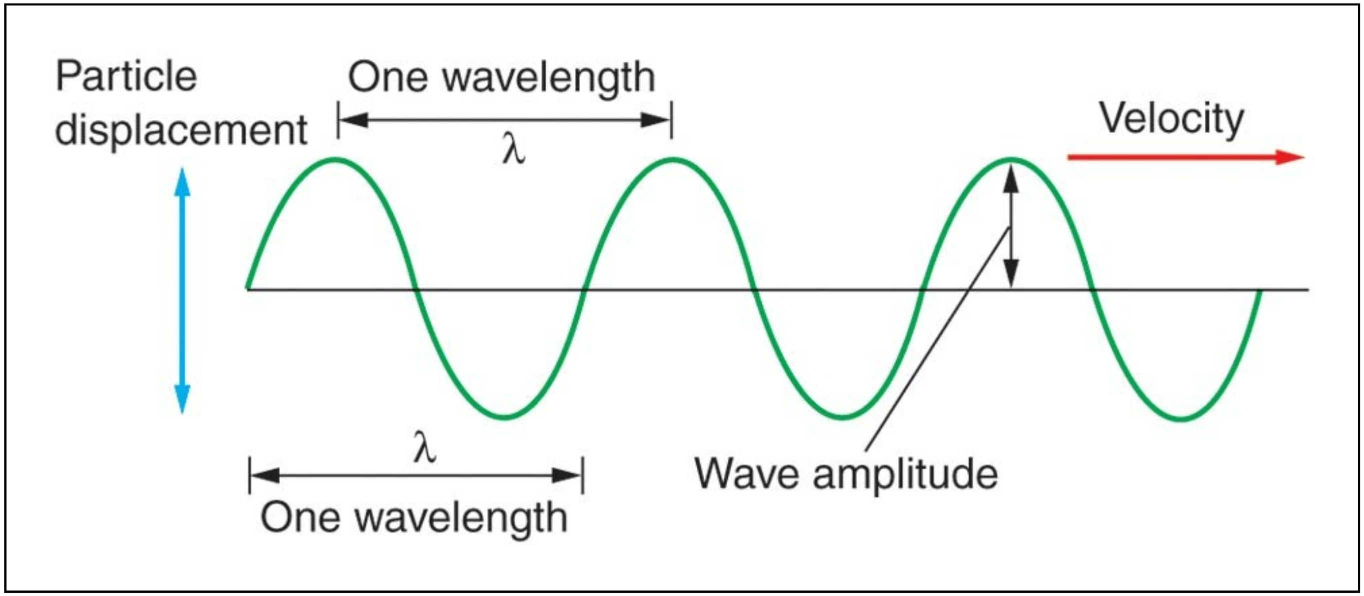
Longitudinal Wave (sound)



Transverse Wave (light)



Wave Description



- <u>Wavelength</u> (λ) – the distance of one complete wave
- <u>Amplitude</u> – the maximum displacement of any part of the wave from its equilibrium position. The energy transmitted by the wave is directly proportional to the amplitude squared.

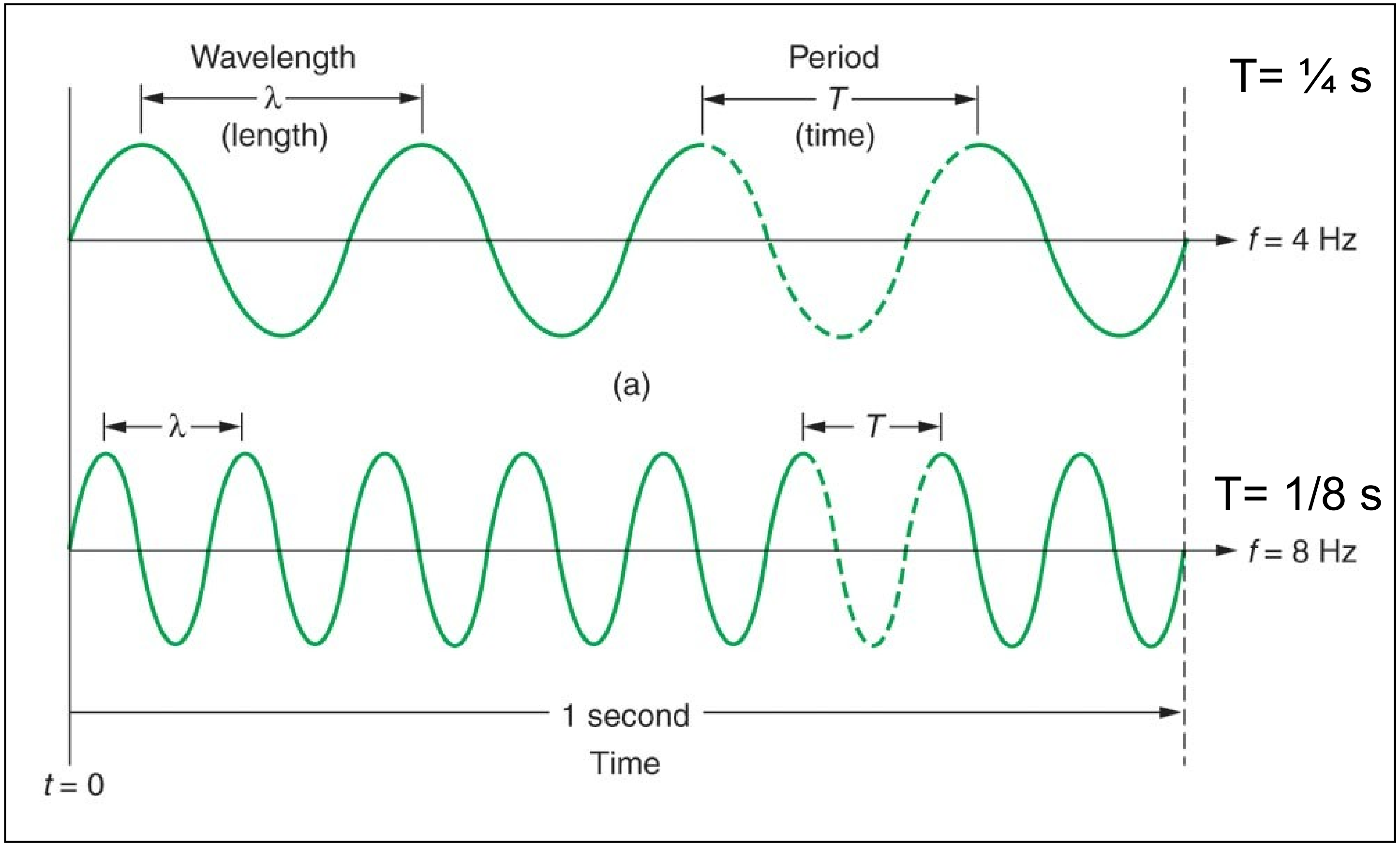
Wave Characterization

- Frequency (f) – the number of oscillations or cycles that occur during a given time (1 s)
  - The unit usually used to describe frequency is the hertz (Hz).
  - One Hz = one cycle per second
- Period (T) – the time it takes for a wave to travel a distance of one wavelength
- Frequency and Period are inversely proportional
- frequency = 1 / period $f = \frac{1}{T}$

Wave Characterization

- Frequency and Period are inversely proportional
- Frequency = cycles per second
  - If a wave has a frequency of $f = 4$ Hz, then four full wavelengths will pass in one second
- Period = seconds per cycle
  - If 4 full wavelengths pass in one second then a wavelength passes every ¼ second ($T = 1/f = ¼$ s)

Wave Comparison



Wave Speed (v)

- Since speed is distance/time then
- $v = \lambda/T$ or $v = \lambda f$
- v = wave speed (m/s)
- λ = wavelength
- T = period of wave (s)
- f = frequency (Hz)

Calculating Wavelengths – Example

- *For sound waves with a speed of 344 m/s and frequencies of (a) 20 Hz and (b) 20 kHz, what is the wavelength of each of these sound waves?*
- GIVEN: v = 344 m/s, (a) f = 20 Hz,
  (b) f = 20 kHz = 20 x 10^3 Hz
- FIND: λ (wavelength)
- Rearrange formula ($v = \lambda f$) to solve for $\lambda = v/f$
  - $\lambda = v/f$ = (344 m/s)/(20 Hz) = 17 m
  - $\lambda = v/f$ = (344 m/s)/(20 x 10^3 Hz) = 0.017 m

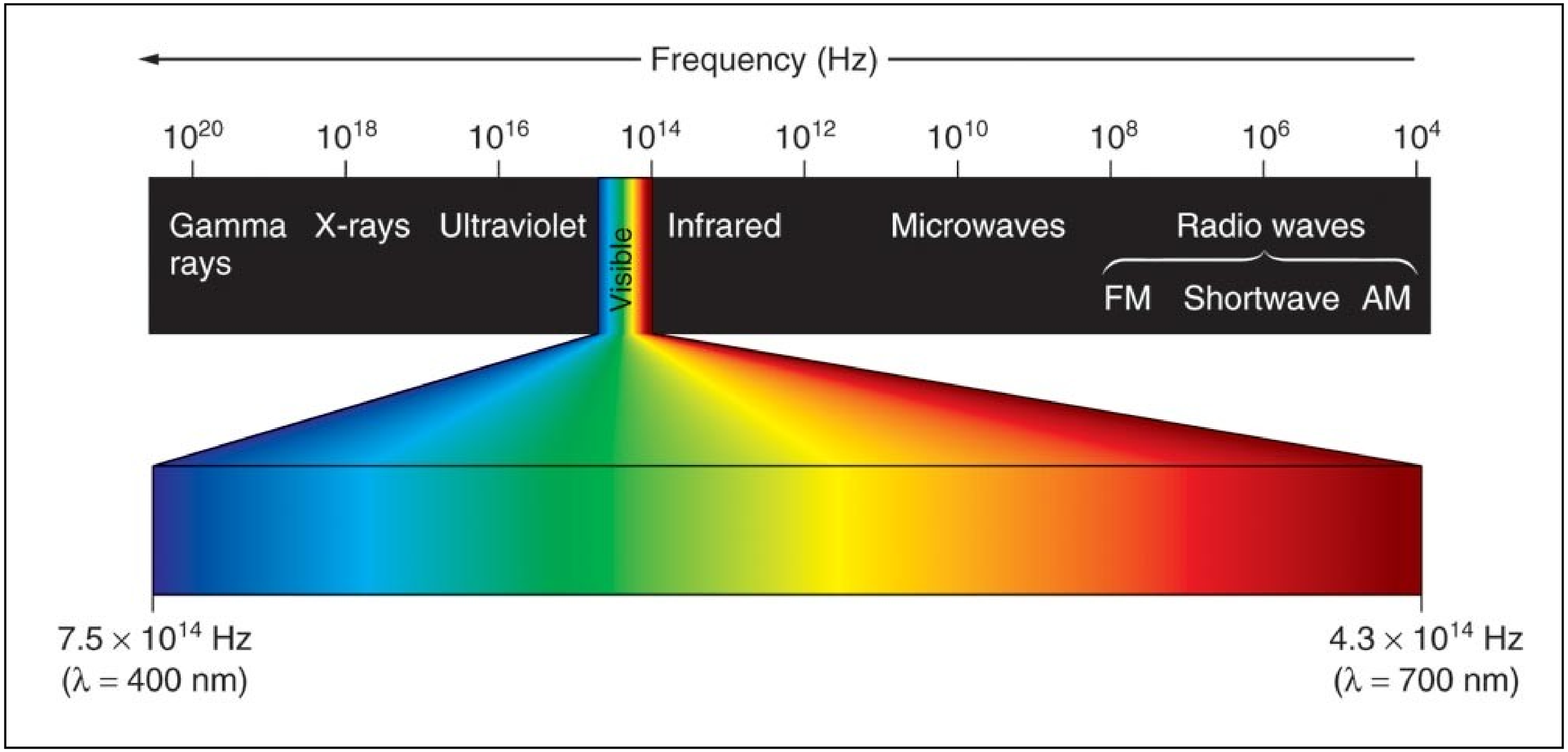
Calculating Frequency Confidence Exercise

- *A sound wave has a speed of 344 m/s and a wavelength of 0.500 m. What is the frequency of the wave?*
- GIVEN: v = 344 m/s, λ = 0.500 m
- FIND: f (wavelength)
- Rearrange formula ($v = \lambda f$) to solve for $f = v/\lambda$
- $f = v/\lambda$ = (344 m/s)/(0.500 m/cycle) =
- f = <u>688 cycles/s</u>

Electromagnetic Waves

- Consist of vibrating electric and magnetic fields that oscillate perpendicular to each other and the direction of wave propagation
- The field energy radiates outward at the speed of light (*c*).
- The speed of all electromagnetic waves ("speed of light") in a vacuum:
  - $c = 3.00 \times 10^8$ m/s $= 1.86 \times 10^5$ mi/s
  - To a good approximation this is also the speed of light in air.

Electromagnetic (EM) Spectrum



The human eye is only sensitive to a very narrow portion of the electromagnetic spectrum (lying between the infrared and ultraviolet.) We call this "light."

Computing Radio Wave Wavelength Example

- *What is the wavelength of the radio waves produced by a station with an assigned frequency of 600 kHz?*
- Convert kHz to Hz:
- f = 600 kHz = 600 x 10^3 Hz = 6.00 x 10^5 Hz
- Rearrange equation ($c = \lambda f$) and solve for λ
- $\lambda = c/f$ = (3.00 x 10^8 m/s)/(6.00 x 10^5 Hz)
- λ = 0.500 x 10^3m = 500 m

Radio Wavelengths: AM vs. FM

- AM approx. = 800 kHz = 8.00×10^5 Hz
- FM approx. = 90.0 MHz = 9.0×10^7 Hz
- Since $\lambda = c/f$, as the denominator (f) gets bigger the wavelength becomes smaller.
- Therefore, AM wavelengths are longer than FM.

Visible Light

- Visible light waves have frequencies in the range of 10^{14} Hz.
- Therefore visible light has relatively short wavelengths.
- $\lambda = c/f = (10^{8}\ \text{m/s})/(10^{14}\ \text{Hz}) = 10^{-6}\ \text{m}$
- Visible light wavelengths ($\sim 10^{-6}$ m) are approximately one millionth of a meter.

Visible Light

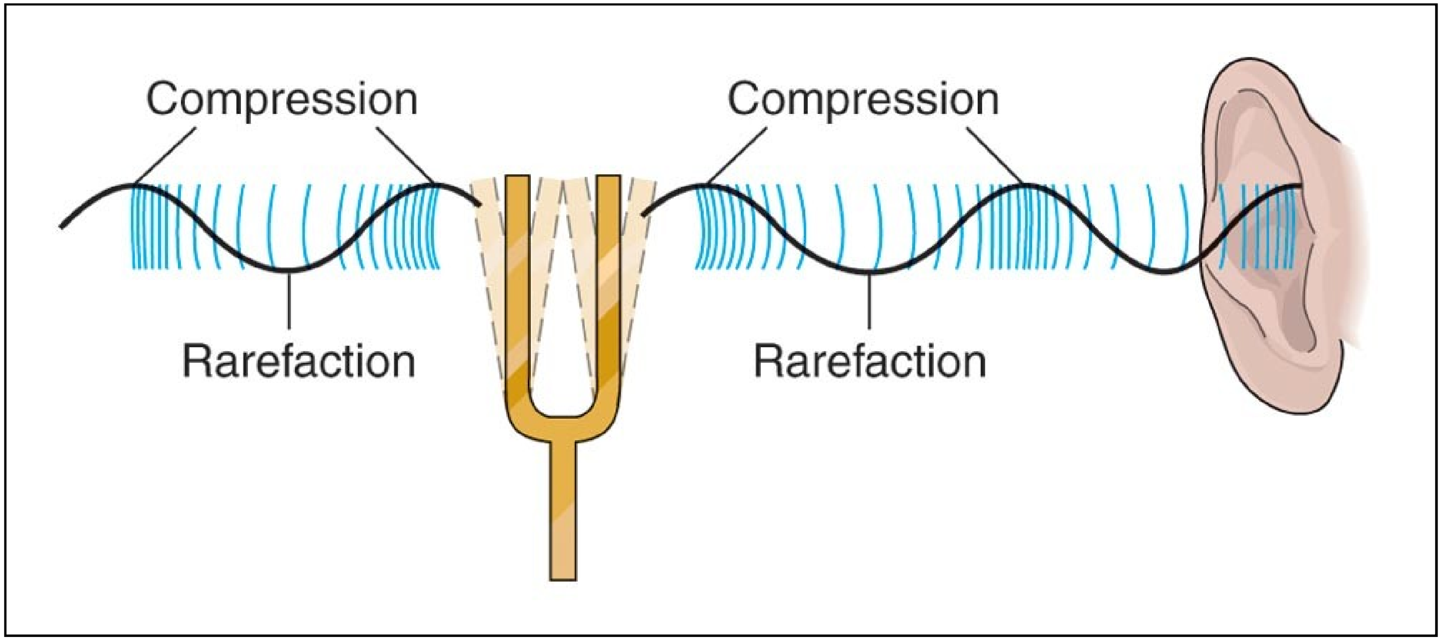
- Visible light is generally expressed in nanometers (1 nm = 10^{-9} m) to avoid using negative exponents.
- The visible light range extends from approximately 400 to 700 nm.
  - 4×10^{-7} to 7×10^{-7} m
- The human eye perceives the different wavelengths within the visible range as different colors.
  - The brightness depends on the energy of the wave.

Sound Waves

- Sound - the propagation of longitudinal waves through matter (solid, liquid, or gas)
- The vibration of a tuning fork produces a series of compressions (high pressure regions) and rarefactions (low pressure regions).
- With continual vibration, a series of high/low pressure regions travel outward forming a longitudinal sound wave.

Audio Link

Tuning Fork



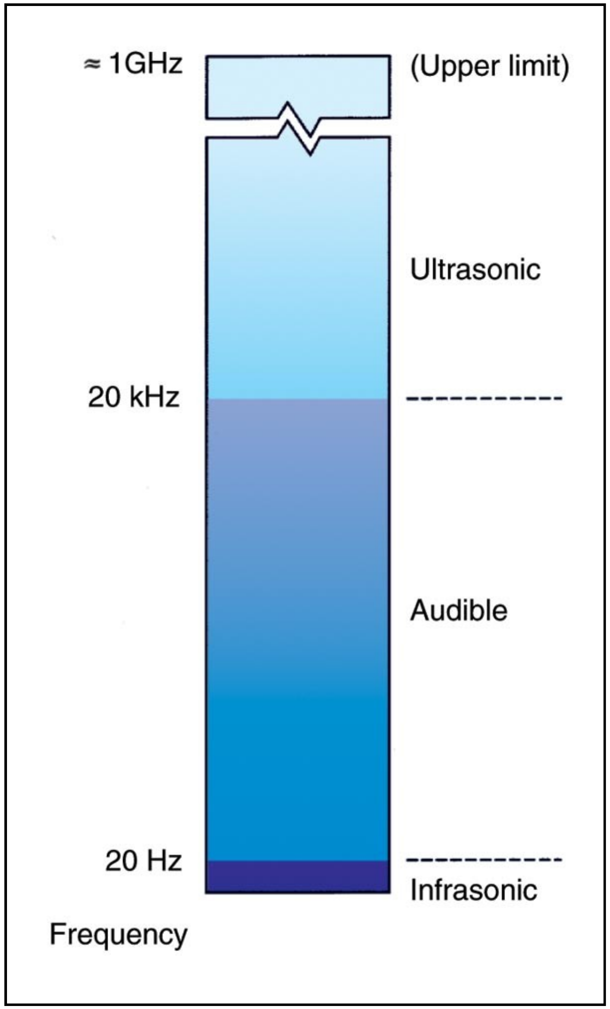
- As the end of the fork moves outward, it compresses the air. When the fork moves back it produces an area of low pressure.

Sound Spectrum

- Similar to the electromagnetic radiation, sound waves also have different frequencies and form a spectrum.
- The sound spectrum has relatively few frequencies and can be divided into three frequency regions:
  - Infrasonic, $f < 20$ Hz
  - Audible, 20 Hz $< f <$ 20 kHz
  - Ultrasonic, $f > 20$ kHz

Audible Region

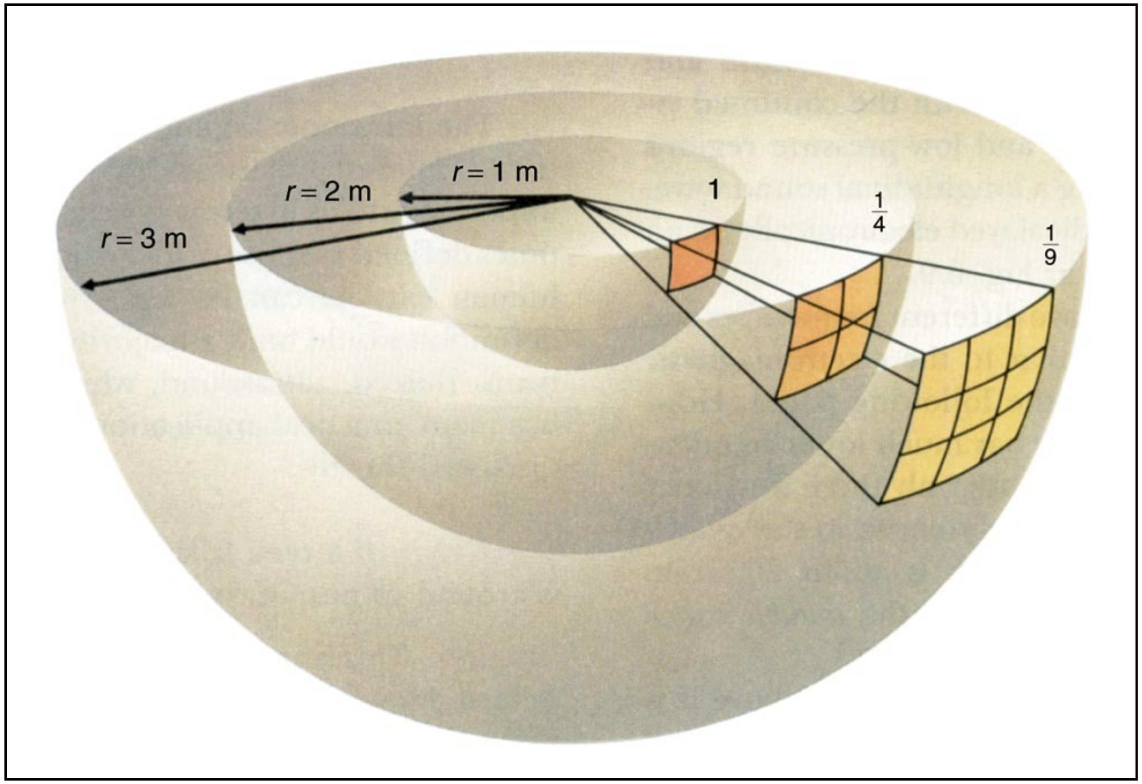
- The audible region for humans is about 20 Hz to 20 kHz.
- Sounds can be heard due to the vibration of our eardrums caused by the sound waves propagating disturbance.



Loudness/Intensity

- Loudness is a relative term.
- The term intensity (I) is quantitative and is a measure of the rate of energy transfer through a given area .
- Intensity is measured in $J/s/m^2$ or W/m^2.
  - The threshold of hearing is around 10^{-12} W/m^2.
  - An intensity of about 1 W/m^2 is painful to the ear.
- Intensity decreases with distance from the source ($I \propto 1/r^2$).
  - This is called an inverse square relation.

Sound Intensity decreases inversely to the square of the distance from source ($I\ \alpha\ 1/r^2$).



Decibel Scale

- Sound Intensity is measured on the decibel scale.
- A decibel is 1/10 of a bel.
  - The bel (B) is a unit of intensity named in honor of Alexander Graham Bell.
- The decibel scale is not linear with respect to intensity, therefore when the sound intensity is doubled, the dB level is only increased by 3 dB.

The Decibel Scale

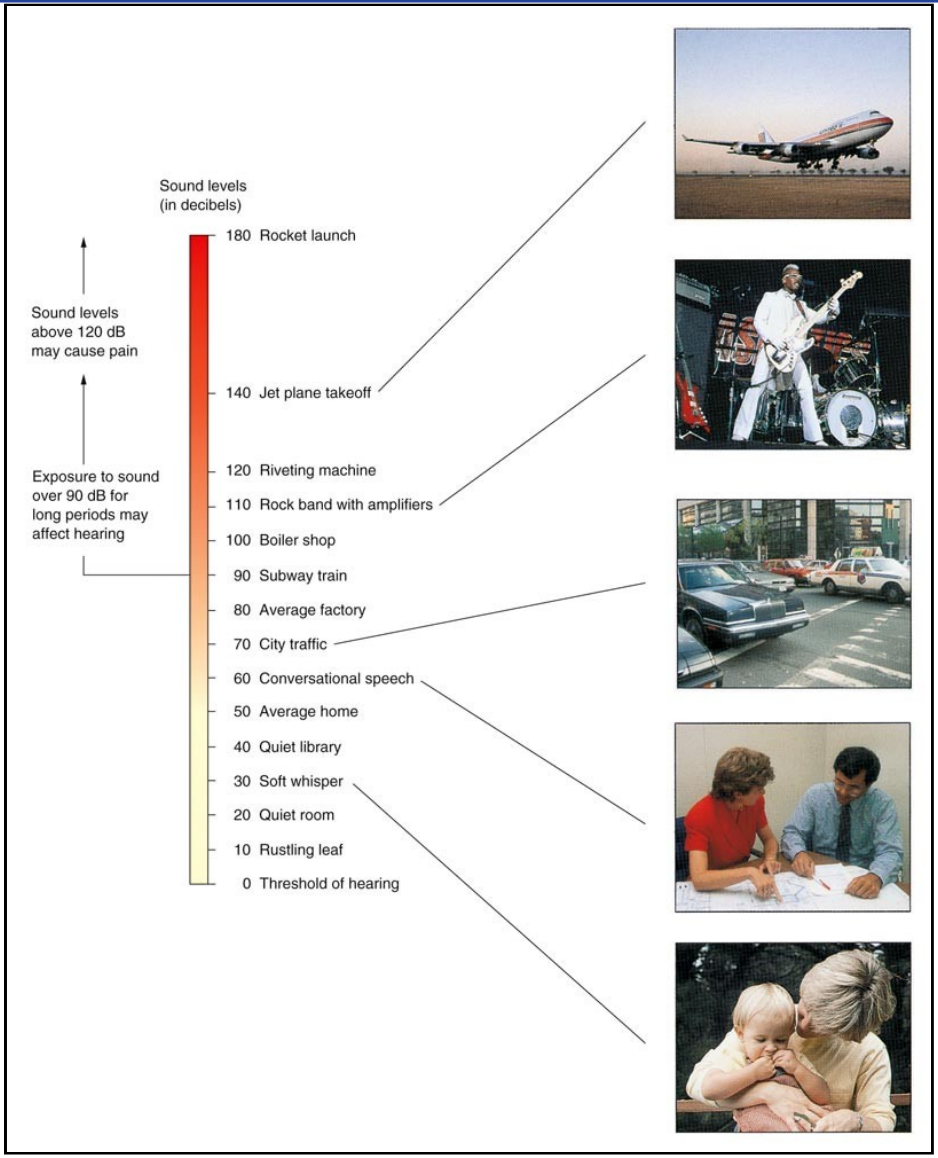


Table 6.1 Sound Intensity Levels and Decibel Differences

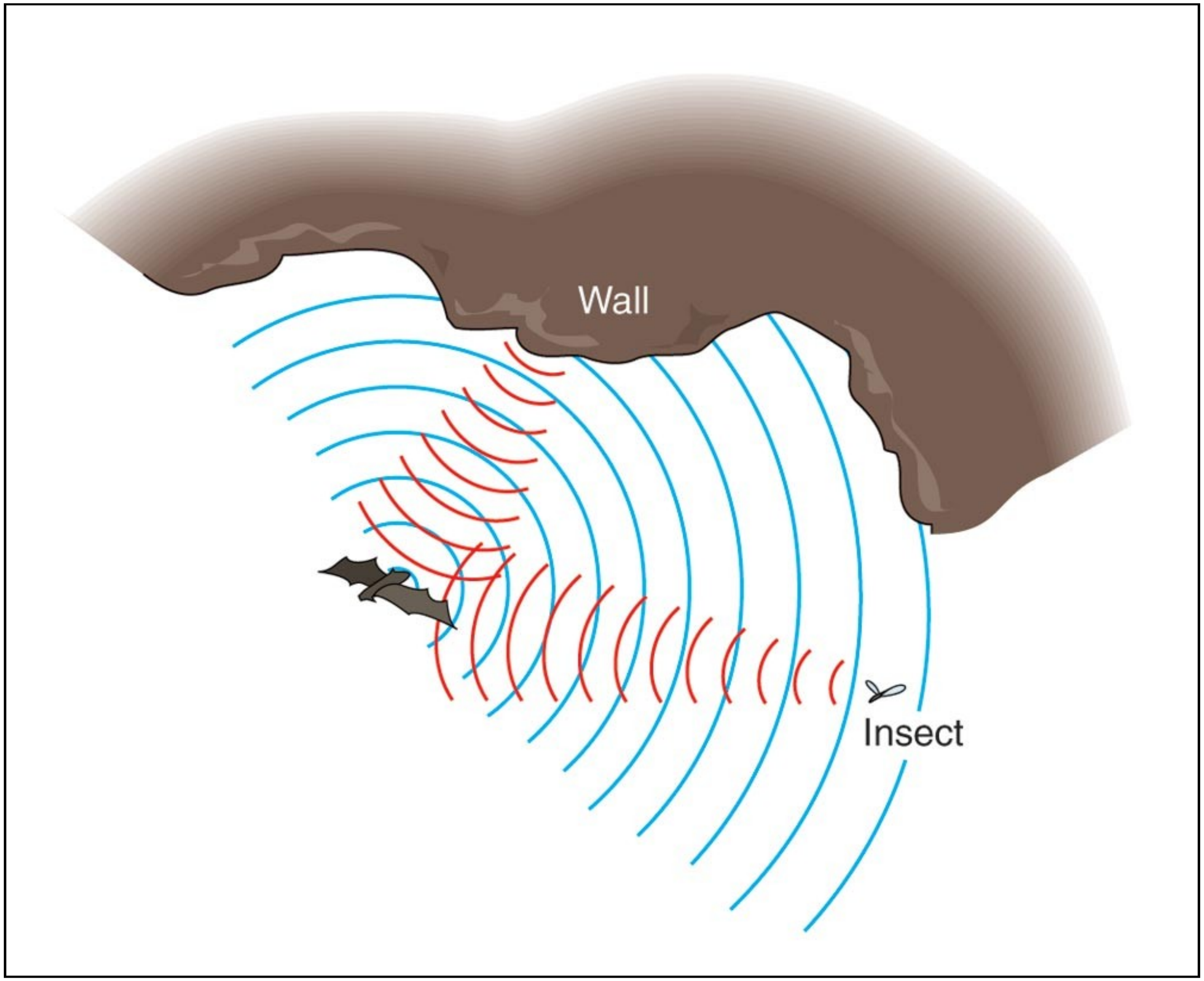
Source of Sound	Sound Intensity Levels (dB)	Times Louder Than Threshold	Decibel Difference (ΔdB)
Riveting machine	120	1,000,000,000,000	—
Rock band with amplifiers	110	100,000,000,000	—
Boiler shop	100	10,000,000,000	—
Subway train	90	1,000,000,000	—
Average factory	80	100,000,000	—
City traffic	70	10,000,000	— (and so on)
Conversational speech	60	1,000,000	Δ60 dB 1,000,000 increase*
Average home	50	100,000	Δ50 dB 100,000 increase
Quiet library	40	10,000	Δ40 dB 10,000 increase
Soft whisper	30	1,000	Δ30 dB 1,000 increase
Quiet room	20	100	Δ20 dB 100 increase
Rustling leaf	10	10	Δ10 dB 10 increase
Threshold of hearing	0	0	Δ3 dB 2 increase

*Similar decreases in intensity occur for −ΔdB.

Ultrasound

- Sound waves with frequencies greater than 20,000 Hz cannot be detected by the human ear, although may be detected by some animals (for example dog whistles).
- The reflections of ultrasound frequencies are used to examine parts of the body, or an unborn child – much less risk than using x-rays.
- Also useful in cleaning small hard-to-reach recesses – jewelry, lab equipment, *etc*.

Bats use the reflections of ultrasound for navigation and to locate food.



Speed of Sound

- The speed of sound depends on the makeup of the particular medium that it is passing through.
- The speed of sound in air is considered to be, v_{sound} = 344 m/s or 770 mi/h (at 20^{o}C).
  - Approximately 1/3 km/s or 1/5 mi/s
- The velocity of sound increases with increasing temperature. (at 0^{o}C = 331 m/s)
- In general the velocity of sound increases as the density of the medium increases. (The speed of sound in water is about 4x that in air.)

Sound

- The speed of light is MUCH faster than the speed of sound. So in many cases we see something before we hear it (lightening/thunder, echo, *etc*.).
- A 5 second lapse between seeing lightening and hearing the thunder indicates that the lightening occur at a distance of approximately 1 mile.

Computing the λ of Ultrasound Example

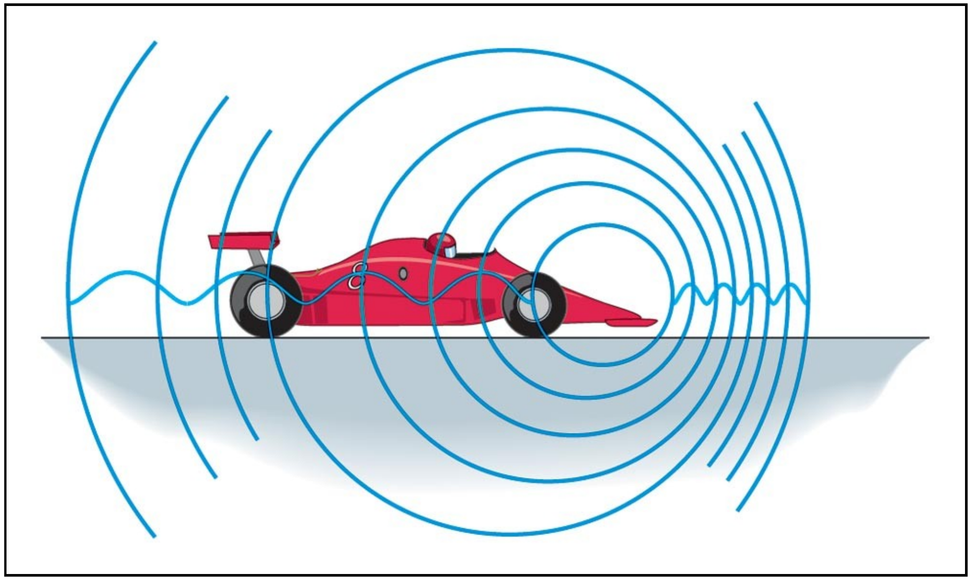
- What is the λ of a sound wave in air at 20^{o}C with a frequency of 22 MHz?
- GIVEN: v_{sound} = 344 m/s and f = 22MHz
- CONVERT: 22 MHz = 22 x 10^6 Hz
- EQUATION: $v_{sound} = \lambda f \rightarrow \lambda = v/f$
  - λ = (344 m/s)/(22 x 10^6 Hz) =
  - λ = (344 m/s)/(22 x 10^6 cycles/s) = 16 x 10^{-6}m

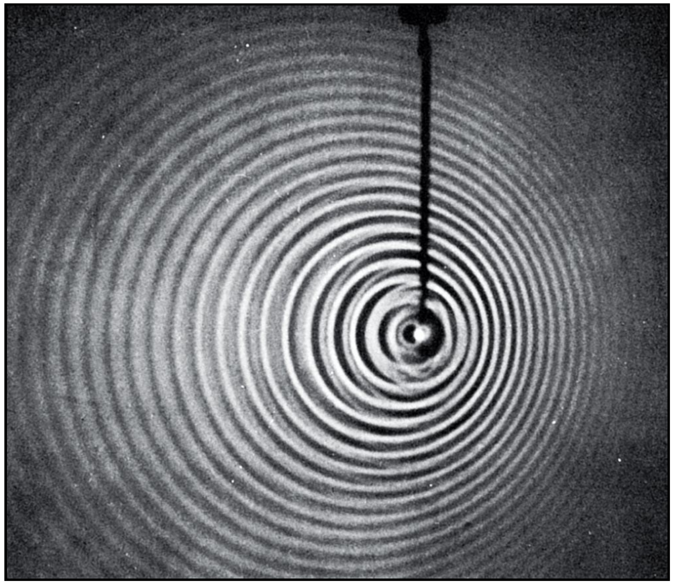
The Doppler Effect

- The Doppler effect - the apparent change in frequency resulting from the relative motion of the source and the observer
- As a moving sound source approaches an observer, the waves in front are bunched up and the waves behind are spread out due to the movement of the sound source.
- The observer hears a higher pitch (shorter λ) as the sound source approaches and then hears a lower pitch (longer λ) as the source departs.

The Doppler Effect Illustrated

- Approach – the waves are bunched up → higher frequency (f)
- Behind – waves are spread out → lower frequency (f)





The Doppler Effects – all kinds of waves

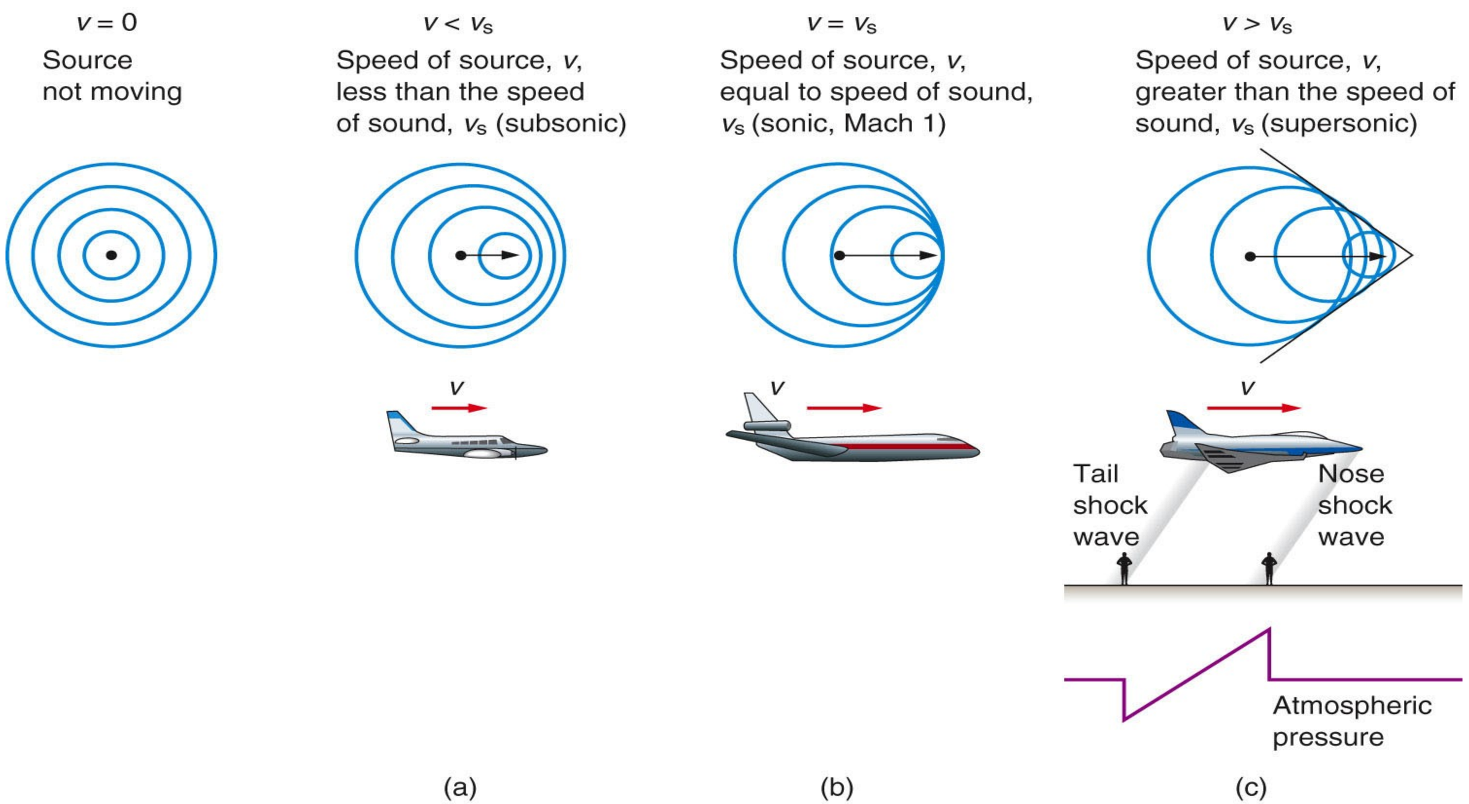
- A general effect that occurs for all kinds of waves – sound, water, electromagnetic
- In the electromagnetic wavelengths the Doppler Effect helps us determine the relative motion of astronomical bodies.
  - 'blue shift' – a shift to shorter λ as a light source approaches the observer
  - 'redshift' – a shift to longer λ as a light source moves away from the observer
- These 'shifts' in λ tell astronomers a great deal about relative movements in space.

Sonic Boom

- Consider the Doppler Effect as a vehicle moves faster and faster.
- The sound waves in front get shorter and shorter, until the vehicle reaches the speed of sound. (approx. 750 mph – depending on temp.)
- As the jet approaches the speed of sound, compressed sound waves and air build up and act as a barrier in front of the plane.

Bow Waves and Sonic Boom

- As a plane exceeds the speed of sound it forms a high-pressure shock wave, heard as a ’sonic boom.’



Mini-Sonic Boom – Crack of a Whip

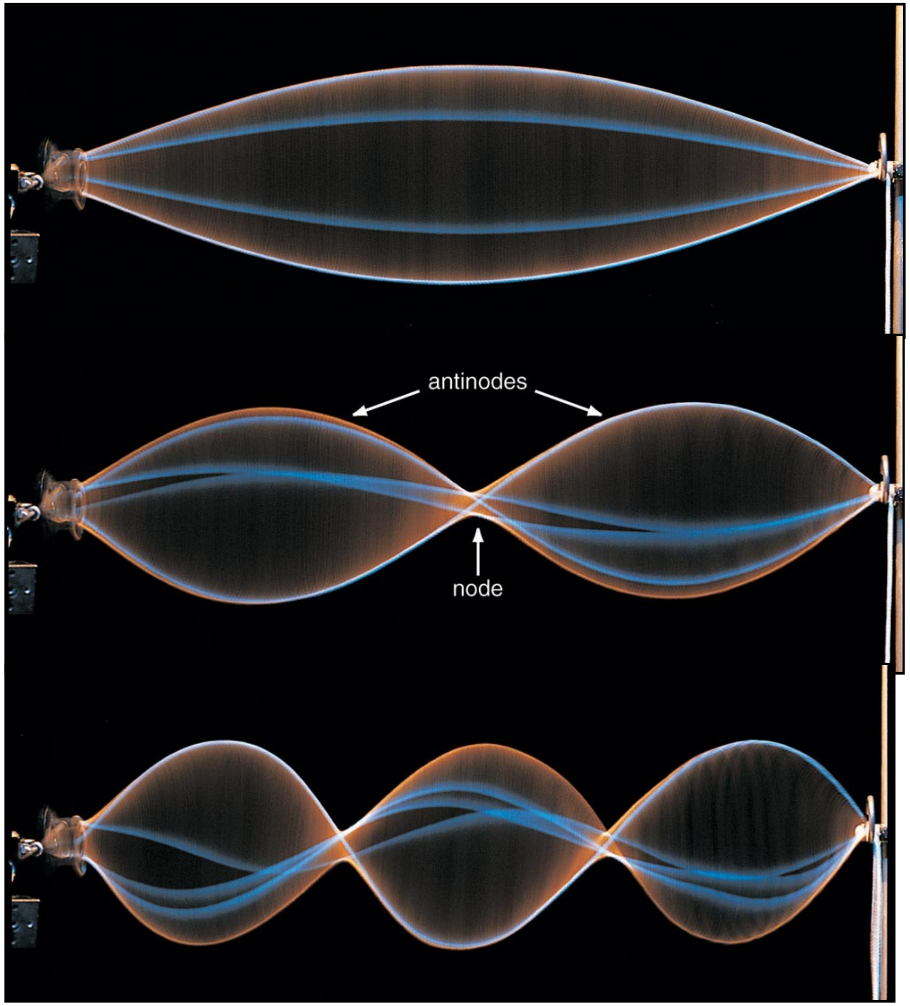
- With the flick of a wrist, a wave pulse travels down a tapering whip.
- The speed of the wave pulse increases as the whip thins, until the pulse is traveling faster than sound.
- The final “crack” is made by air rushing back into the area of reduced pressure, created by the supersonic final flip of the whip’s tip.

Standing Waves

- <u>Standing wave</u> – a “stationary” waveform arising from the interference of waves traveling in opposite directions
- Along a rope/string, for example, waves will travel back and forth.
  - When these two waves meet they constructively “interfere” with each other, forming a combined and standing waveform.

Standing Waves

- Standing waves are formed only when the string is vibrated at particular frequencies.

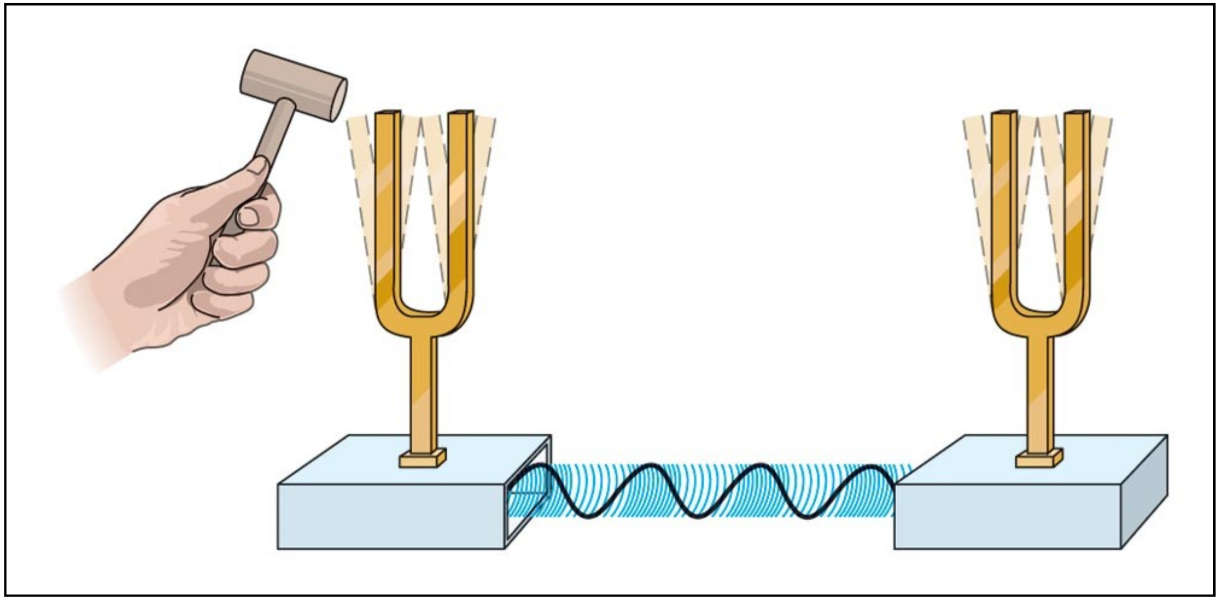


Resonance

- Resonance - a wave effect that occurs when an object has a natural frequency that corresponds to an external frequency.
  - Results from a periodic driving force with a frequency equal to one of the natural frequencies.
- Common example of resonance: Pushing a swing – the periodic driving force (the push) must be at a certain frequency to keep the swing going

Here are two links that do a really nice job with resonance.
http://www.youtube.com/watch?v=BE827gwnnk4
http://www.youtube.com/watch?v=wvJAgrUBF4w

Resonance



- When one tuning fork is struck, the other tuning fork of the same frequency will also vibrate in resonance.
- The periodic “driving force” here are the sound waves.

Musical Instruments

- Musical Instruments use standing waves and resonance to produce different tones.
- Guitars, violins, and pianos all use standing waves to produce tones.
- Stringed instruments are tuned by adjusting the tension of the strings.
  - Adjustment of the tension changes the frequency at which the string vibrates.
- The body of the stringed instrument acts as a resonance cavity to amplify the sound.

Chapter 6 - Important Equations

- $f = 1/T$ Frequency-Period Relationship
- $v = \lambda/T = \lambda f$ Wave speed
- 3.00×10^8 m/s Speed of Light