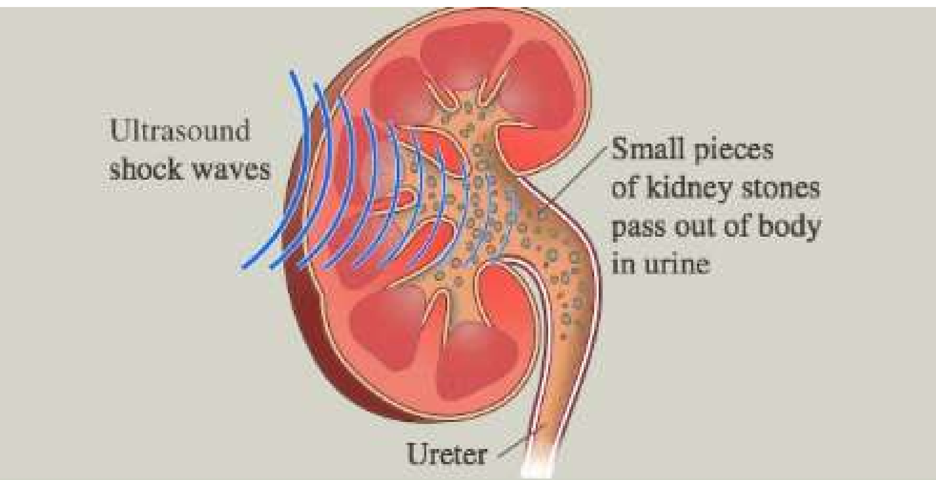
Waves and Sound

Waves and Sound - Lithotripter

Lithotripter



Waves and Sound

Waves are transfer of energy yet do not have mass.

The substance through which waves travel is called medium of the wave.

Definition: **Wave** A travelling disturbance consisting of coordinated vibrations that transmit energy with no net movement of matter.

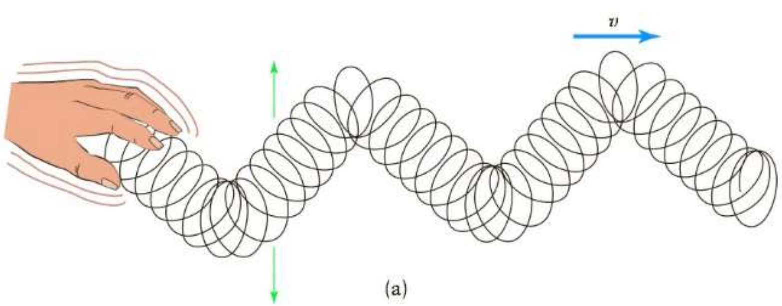
Many waves require a medium to travel such as sound waves (sonar), water ripples, but these CAN NOT propagate in Vacuum.
Other type of waves such as light, x-rays, microwaves, DO NOT require a medium to propagate, and CAN propagate in vacuum. Electromagnetic waves will be discussed in details in Chapter – 8 This chapter is a pre-requisite

Wave Types & Speed

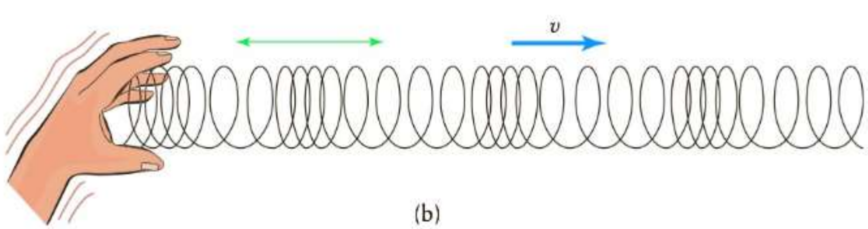
Definition: **Transverse Wave:** A wave in which the oscillations are **perpendicular** to the direction of the wave travel.

Longitudinal Wave: A wave in which the oscillations are **along** the direction the wave travels.

Transverse Wave	Longitudinal Wave
Rope Electromagnetic Slinky / Spring Earthquakes	Sound in the air Water in pipes Fluids in syringes Slinky / Spring Earthquakes



(a)

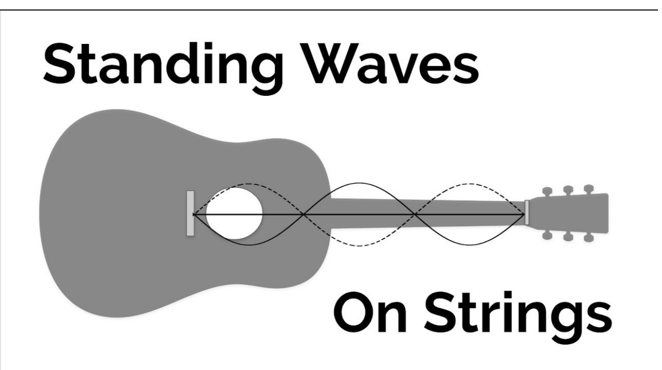


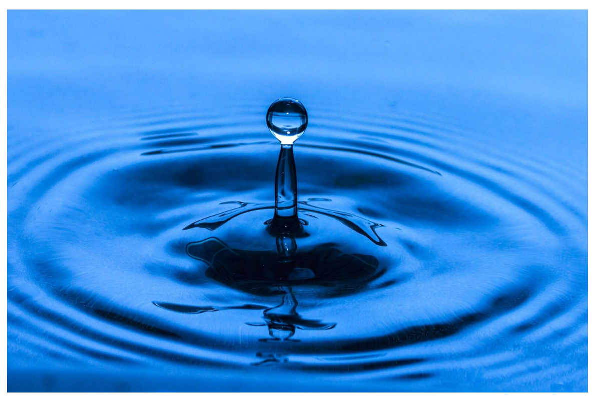
(b)

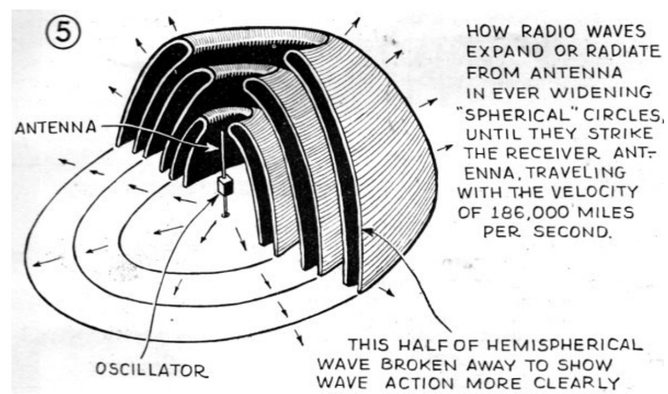
Wave Types & Speed

Waves could propagate in 1D, 2D, or 3D.

1-D Waves	2-D Waves	3-D Waves
Rope String Slinky Spring	ripples	Radio Antenna Heat Rays







Wave Speed

The speed of wave is the rate of movement of the disturbance

The speed of wave propagation could be predicted by measuring other properties of the medium. i.e. on a Rope or Slinky, ρ called linear mass density which is ratio of the mass and the length or ρ = m/l. (chapter 4 is volume density)

$$v = \sqrt{F/\rho}$$

The speed of sound in air depends on the ratio of pressure of the gas to the density of the gas. After simplification, the ratio depends only on Temperature (in Kelvin). So the speed of sound in air formula

$$v = 20.1 * \sqrt{T}$$

Units: Wave Speed : v m/s, mph

Speed of Sound different temperature

What is the speed of sound in air in m/s then in mph. Under the following conditions:

a) Ambient nice day 68F
b) Inside a freezer 32F
c) Nearby a heater at 140F
d) Very Cold day -40F
e) Inside brick oven pizza at 850F

Speed of Sound different materials

Knowing that speed of sound in air is $v = 20.1 * \sqrt{T}$, in Helium = $v = 58.8 * \sqrt{T}$ and in CO_2 $v = 15.7 * \sqrt{T}$:

Compute the speed of sound at 3 different gases at 68F, then sort them in decreasing order

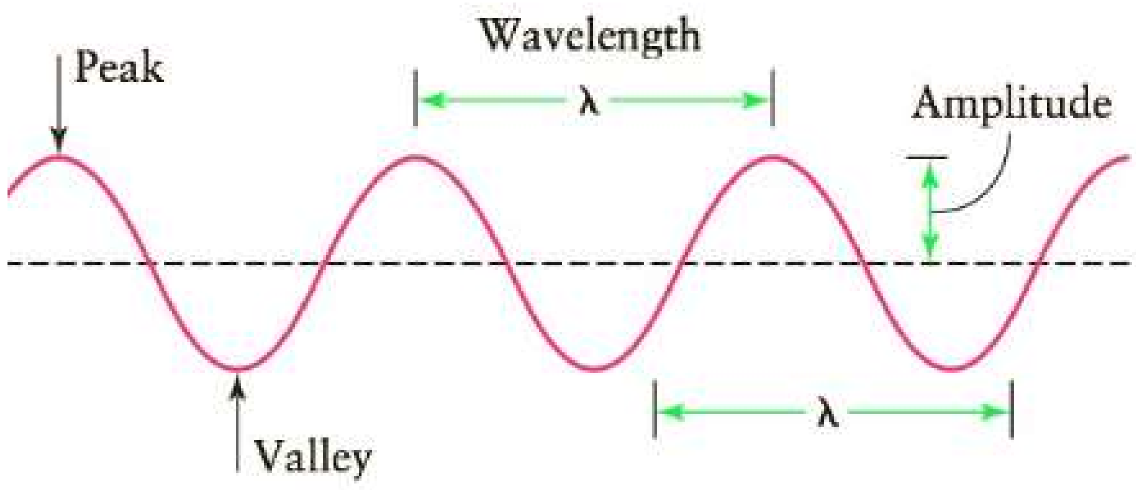
Amplitude, Wavelength, and Frequency

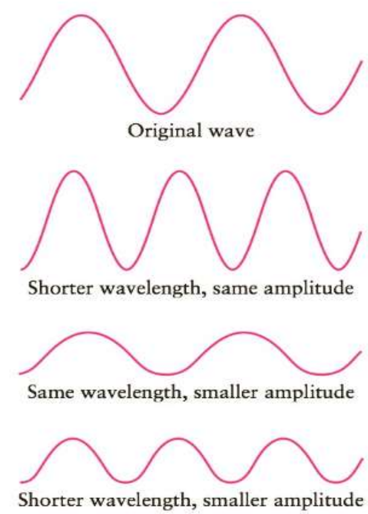
Definition: **Amplitude:** The maximum displacement of points from equilibrium .

Wavelength: Lambda *λ* The distance between 2 “like” points on a wave (PTP, VTV).

For an idealized model **sinusoidal shape**, easy and important terminology to understand.

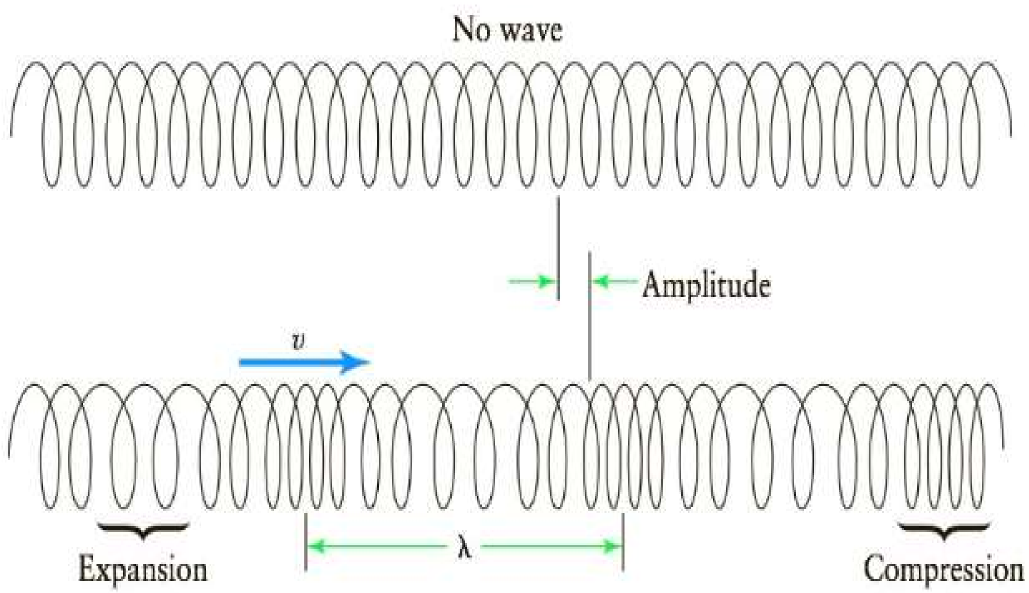
Peak or Crest, Valley or Throughs.
The dashed line represents the **equilibrium**, and Amplitude is the distance between the equilibrium position and the maximum or (Peak-Valley)/ 2. A full wavelength represents a whole ***cycle***, PTP, VTV, 0T0. The **frequency** is number of events per unit time.





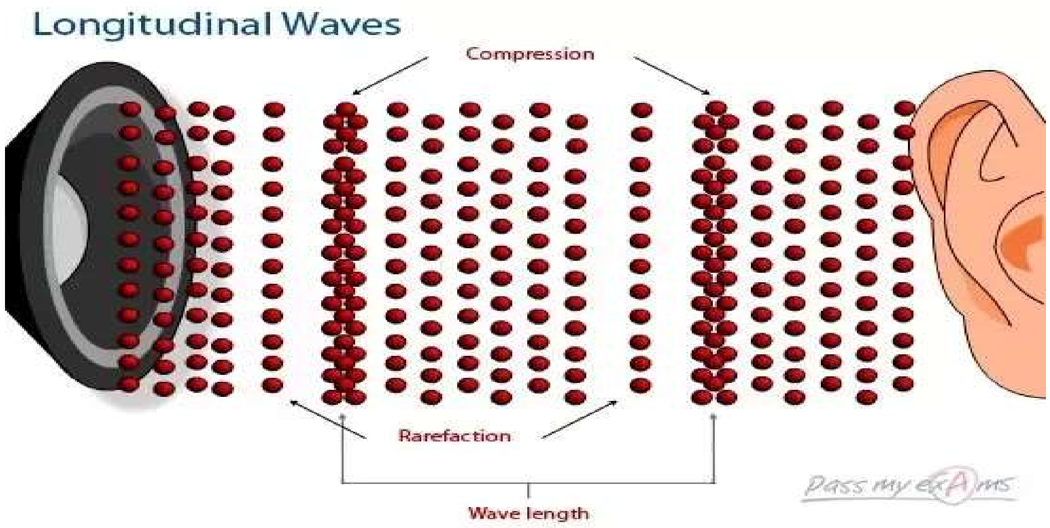
Amplitude, Wavelength, and Frequency

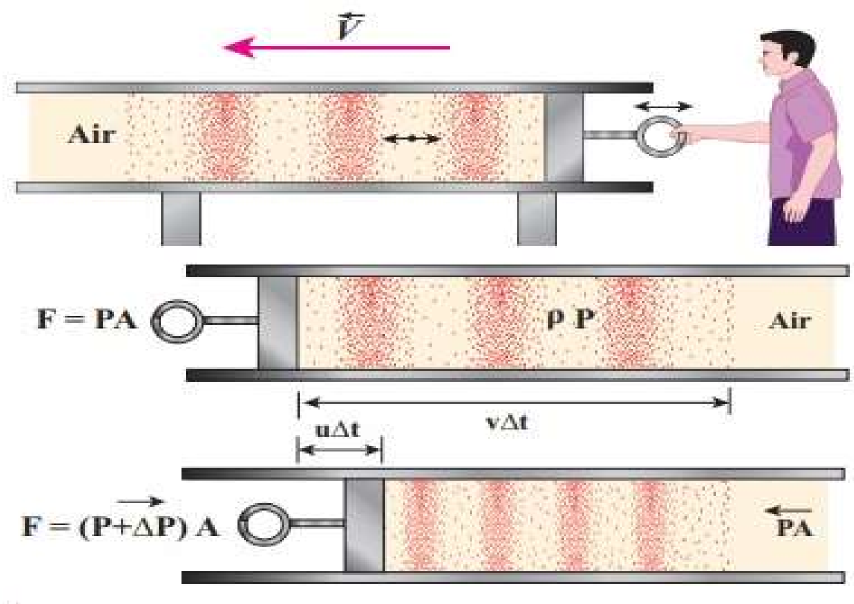
Longitudinal Waves are not easy to visualize yet have the same concept. I.e. zones of expansion (valley) and zones of compression (peak). Amplitude, and Wavelength are similarly identified. Still the concept of energy travel without mass.



Amplitude, Wavelength, and Frequency

Another example of Longitudinal Waves in fluids (liquids and gases) is shown, notice the compression and expansion (refraction) areas.





Amplitude, Wavelength, and Frequency

The speed of a wave = number of cycles per cycle (f) times the length of each cycle lambda.

In spoken English, the number of each that passes by a second times the length of each cycle.

$$v = f * \lambda$$

Simplified assumptions to memorize about sound waves:

- Two sound waves traveling through air have 2 different frequencies, consequently they must have 2 different wavelengths.
- The only way to make sound travel faster in air is to increase air temperature.

$$v = 20.1 * \sqrt{T}$$

Units: Wave Speed : v (m/s, mph), frequency f (Hz, or 1/s), Wavelength λ(m)

Waves speed

The frequency of 4Hz continuous wave travels on a Slinky. If the wavelength is 0.5 m, what is the speed of propagation on the Slinky?

Waves speed

A wave traveling 80 m/s has a wavelength of 3.2 m. What is the frequency of the wave?

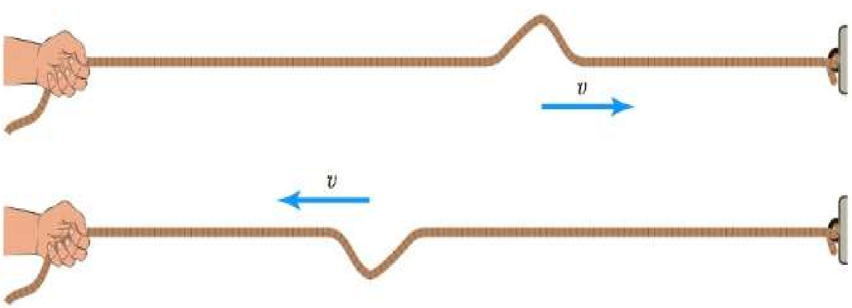
Reflection

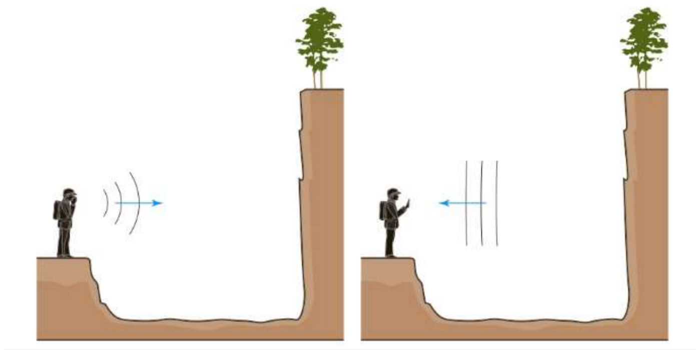
A wave is reflected whenever it reaches a boundary or its medium encounters an abrupt change in the properties i.e. density.

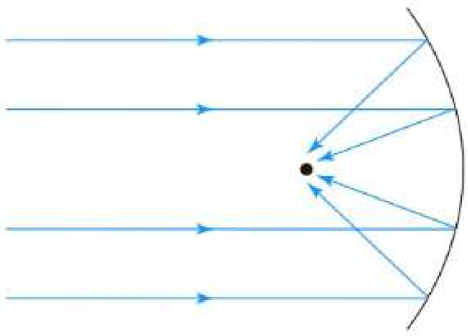
A pulse traveling on rope “bounces” is reflected when it reaches an anchored end.

Echo is also a reflected wave and is critical to many phenomena i.e. Sonars

Special note: Typically waves amplitudes **attenuate** and get smaller. Willingly we reflect waves on a specific point, **focus**, which will **add** the amplitudes making a gigantic magnitude – **parabola**, sun ray focus etc...







Sonography

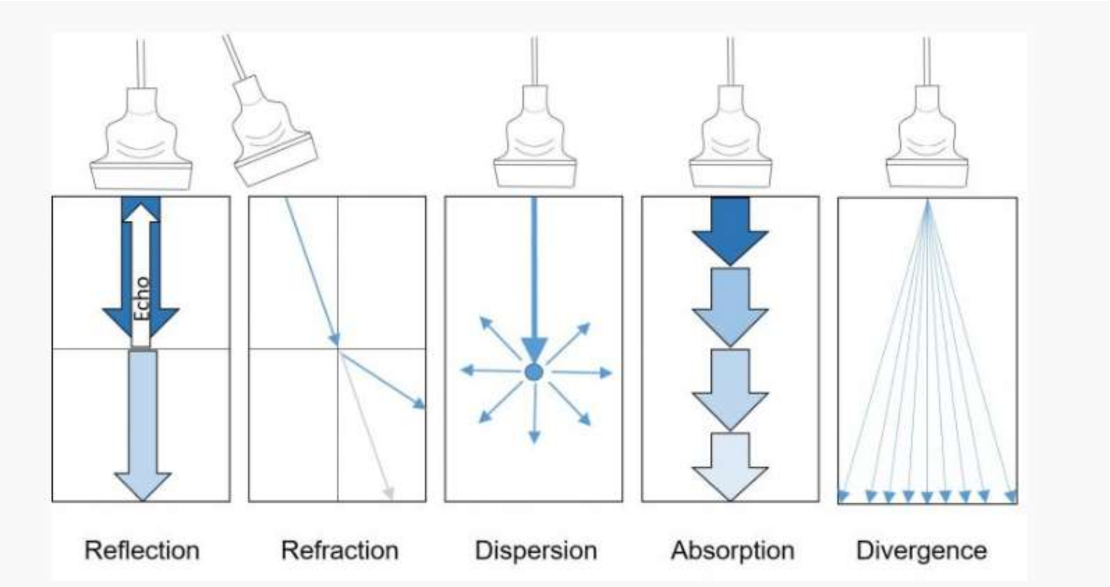
There are many types of waves and sound is a special application. Sound is Sono in French

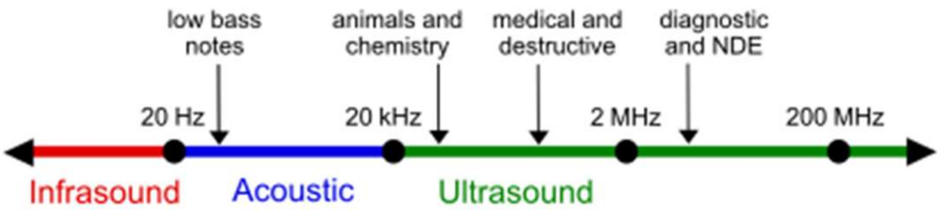
Shown is the speed of Sound through different medium material.

Tissue	Air	Water	Muscle	Fat	Liver	Spleen	Kidney	Bone
V (m/s)	331	1496	1568	1476	1570	1565	1560	3360

A normal person could hear frequencies as low as 20Hz up to 20,000Hz

Ultrasound starts above 20,000Hz



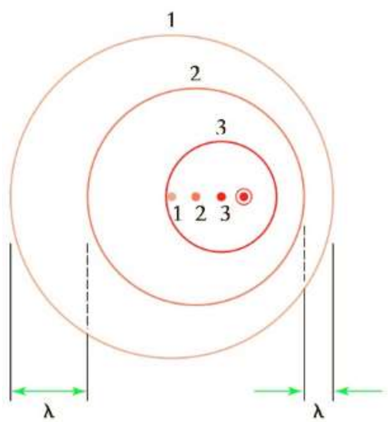


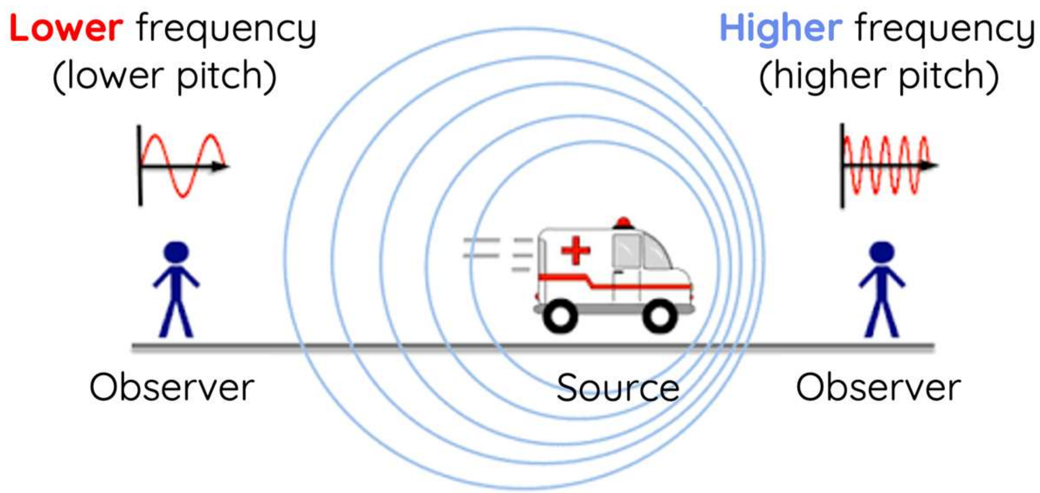
Doppler Effect

The doppler effect happens when the wave source is **moving**, or when you are **moving** from the wave source.

This causes **shorter wavelength** in the direction of the moving source and **longer wavelength** behind the moving source.

Since the speed of the wave is constant, where the wavelength goes up the frequency must go down and vice versa.



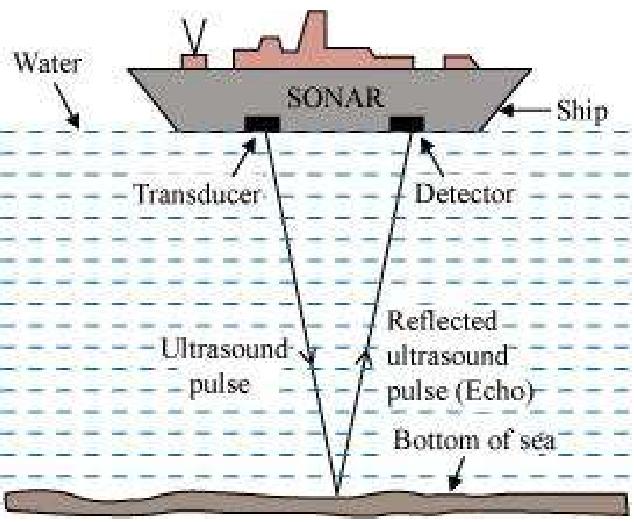


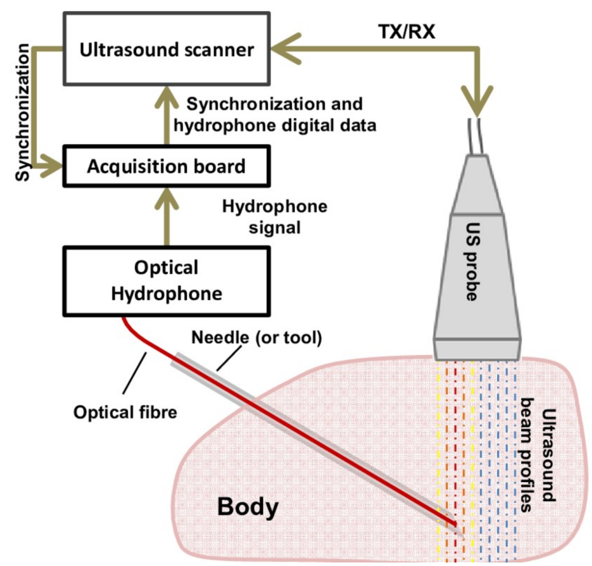
Speed of Sound

In a student laboratory exercise, the wavelength of a 40,000-Hz ultrasound wave is measured to be 0.868 cm. What is the air temperature in F?

Echolocation

It is the process of using **waves bounced "reflected"** from an object to determine its location. Sonar & Radar work on this principle.
The time between the emission and detection "reflection" could tell us how far (distance) is the object.





Speed of Sound

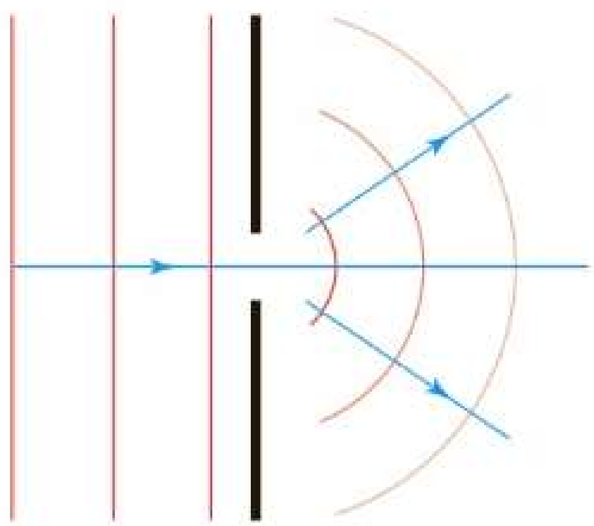
Ultrasound probes can resolve structural details with sizes approximately equal to the wavelength of the ultrasound waves themselves.

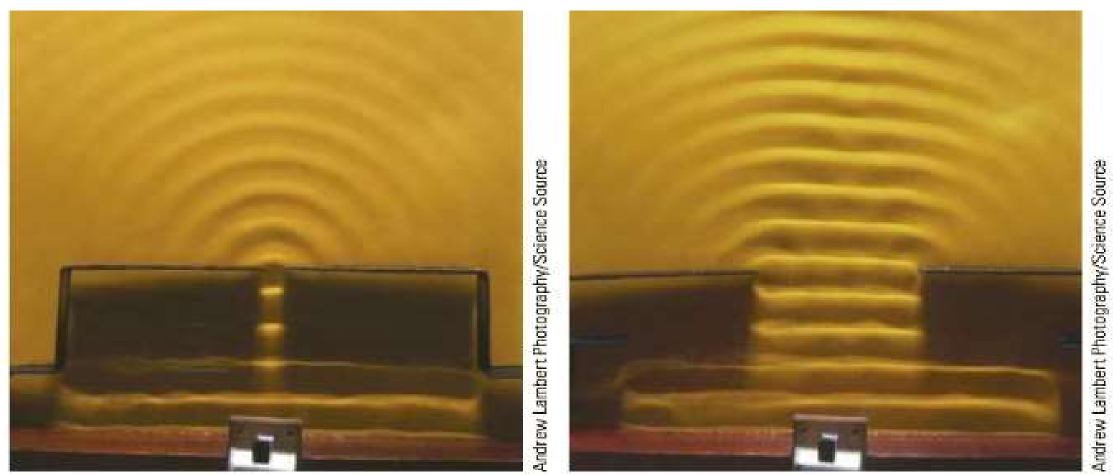
What is the size of the smallest feature observable in human tissue when examined with 20-MHz ultrasound? The speed of sound in human tissue is 1,540 m/s.

Diffraction

Diffraction is when a wave hits a gap in its trajectory. Diffraction is different than reflection – ideally is shown in water ripples.

The ratio of the gap (opening) to the wavelength alters the behavior of diffraction. When the opening is larger than the wavelength there is little diffraction. When the opening is smaller than the wavelength diffraction is amplified.

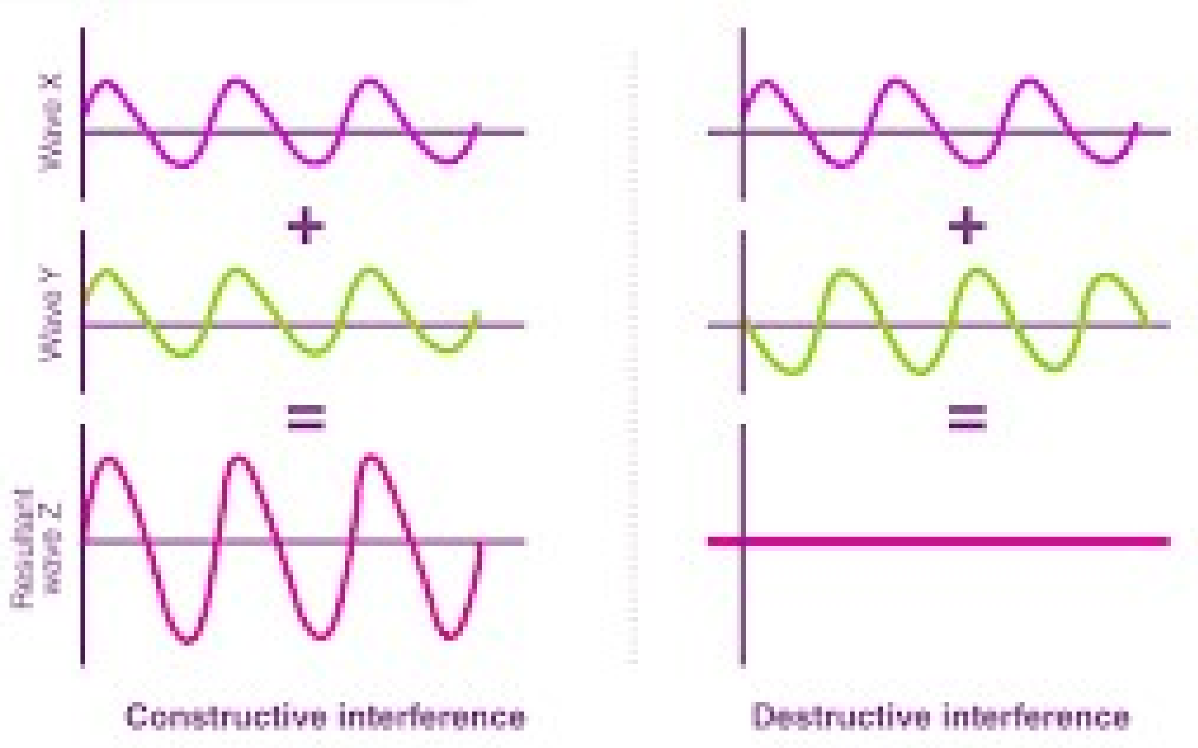


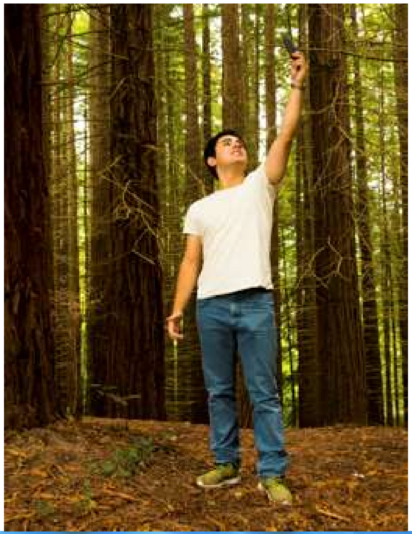


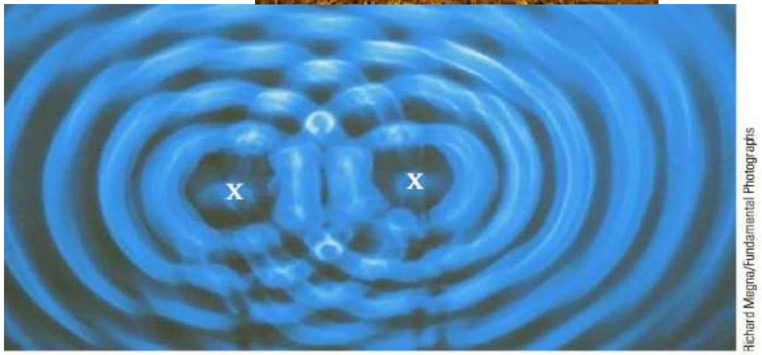
Interference

What happens when 2 or more waves encounter each other.

The simple answer is their amplitudes are added together – depending on the circumstance they could be constructive or destructive.



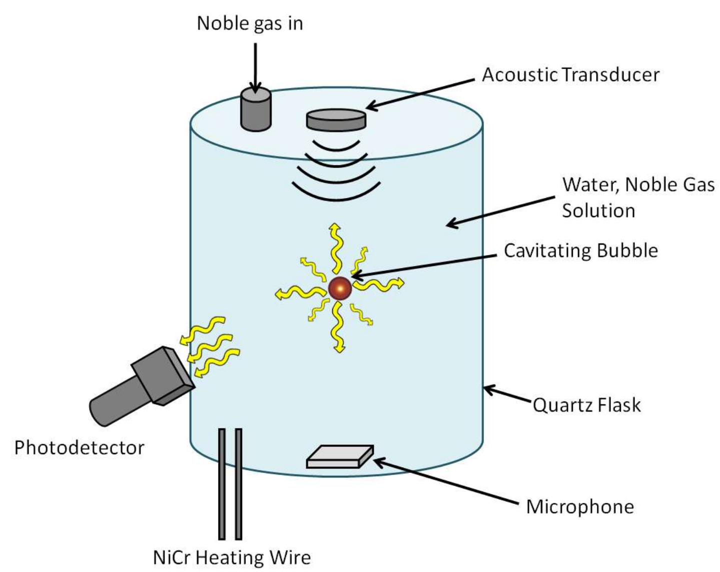




Ultrasound

Ultrasound around 3.5 Million Hz is sent into the body and partially reflected. Waves characteristics, speed, amplitude, reflections, additions, manipulation, and calculations, are made to make an image shown on a monitor.

These are the basics, Sonographers and Doctors must master fundamentals for good interpretations and better analysis and advise.



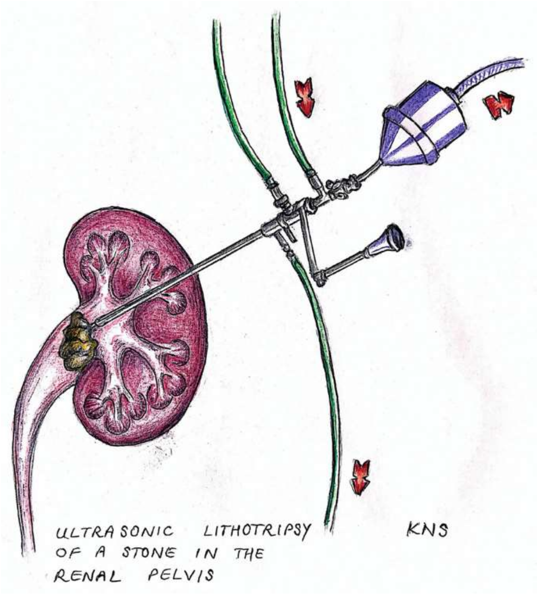
Wave Types & Speed

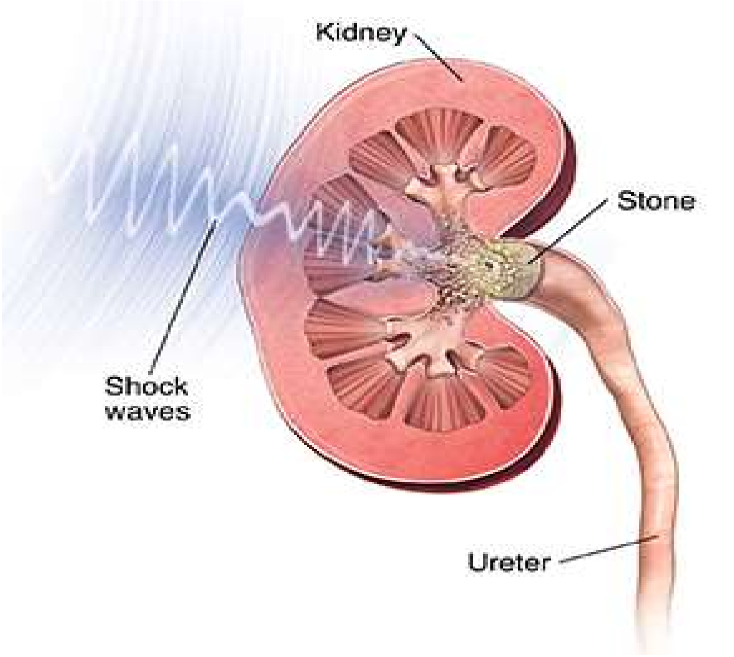
What is the wavelength of 3.5 million Hz ultrasound as it travels through human tissue knowing that the speed of sound through human tissue is 1540m/s?

Ultrasonic Lithotripsy

This Ultrasonic Technique is used to break kidney stones. This technique is based on inserting a steel tube that get in contact with kidney stones, the tube emits large-amplitude waves that shatters stones the frequency is around 24,000Hz.

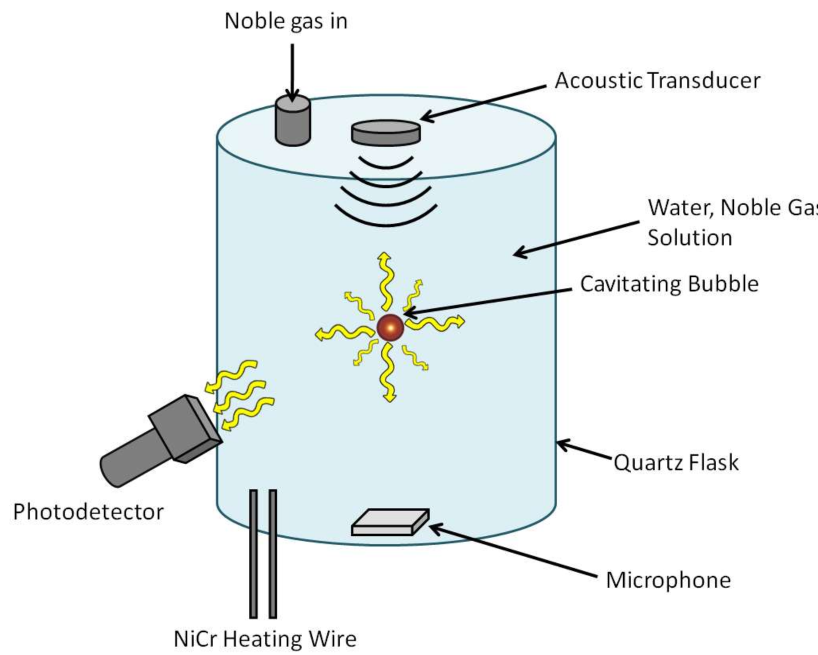
Note that these wave are in direct contact with the stone and no contact with other body organs or tissues unlike shock wave for EWSL (Extracorporeal shock wave lithotripsy).





Ultrasound

Ultrasound around 3.5 Million Hz is sent into the body and partially reflected. These reflections are synthesized, manipulated, and reconstructed to make an image by Sonographers and Doctors for the well being of humanity. Ultrasound can produce light. Sonoluminescence, a bubble inside water emits flashes of light as pressure oscillations caused by sound waves with frequencies around 26,000 Hz.



Summary

- Waves are everywhere. They can be classified as **transverse** or **longitudinal** according to the orientation of the wave oscillations relative to the direction of wave propagation.
- The speed of a wave depends on the properties of the medium through which it travels. For continuous periodic waves, the product of the **frequency** and the **wavelength** equals the wave speed.
- Once waves are produced, they are often modified as they propagate. **Reflection** and **diffraction** cause waves to change their direction of motion when they encounter boundaries.
- **Interference** of two waves produces alternating regions of larger-amplitude and smaller or zero-amplitude waves.
- The **Doppler effect** and the formation of **shock** waves are phenomena associated with moving wave sources. The former also occurs when the receiver of the waves is moving.
- Although sound can refer to a broad range of mechanical waves in all types of matter, we often restrict the term to the longitudinal waves in air that we can hear. Sound waves in air are generally represented by the air-pressure fluctuations associated with the **compressions** and **expansions** in the wave.
- Sound with frequencies too high to be heard by humans, above about 20,000 hertz, is called **ultrasound**. Ultrasound is used for echolocation by bats and for a variety of procedures in medicine. Sound with frequencies too low to hear, below about 20 hertz, is called **infrasound** and is used by some large mammals for communication.
- The sounds that we can hear in the range 20 Hz to 20,000 Hz can be divided into **pure tones**, **complex tones**, and **noise** according to the shapes of their **waveforms**.
- Sound is produced in many different ways, all resulting in rapid pressure fluctuations that travel as a wave. Different musical instruments employ diverse and sometimes multiple sound-production mechanisms, including vibrating plates or membranes, vibrating strings, or vibrating columns of air in tubes.
- Sound propagation inside rooms and other enclosures is dominated by repeated reflection, called **reverberation**. This causes individual sounds to linger after they are produced. Moderate reverberation causes a positive blending of successive sounds, such as musical notes, but too much reverberation can adversely affect the clarity of speech.
- We use three main characteristics to classify a steady sound we perceive: **pitch**, **loudness**, and **tone quality**. The pitch of a sound depends mainly on the frequency of the sound wave.
- The loudness of a sound depends mainly on the amplitude (or **sound level**) of the sound, but it is also affected by the frequency.
- The tone quality of a sound depends on the **waveform** of the sound wave. The waveform of a complex tone depends on the number and amplitudes of the separate pure tones, called **harmonics**, that comprise it.

Equations

Equation	Comments	Equation	Comments
$\rho = \frac{m}{l}$	Linear mass density of rope, wire, string, Slinky, etc.	$v = f\lambda$	Relates frequency, wavelength, and speed for continuous waves
$v = \sqrt{\frac{F}{\rho}}$	Speed of waves on linear media (a rope, wire, string, Slinky, etc.)	$v = H_0 d$	Hubble relation for expansion of the universe
$v = 20.1 \times \sqrt{T}$	Speed of sound waves in air (SI units)	$\text{amplitude} \propto \frac{1}{d}$	Dependence of sound amplitude on distance