## From Last Time… Wave Properties

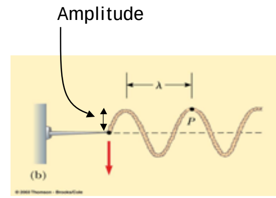
- **Amplitude** is the maximum displacement from the equilibrium position
- **Wavelength**, $\lambda$, is the distance between two successive points that behave identically
- **Period**: time required to complete one cycle
- **Frequency** = 1/Period = rate at which cycles are completed

- Velocity = Wavelength/Period, $v = \lambda / T$, or $v = \lambda f$



## Description of a Wave

- Amplitude is the maximum displacement of string above the equilibrium position
- Wavelength, $\lambda$, is the distance between two successive points that behave identically




- For instance, the distance between two crests



## More types of waves

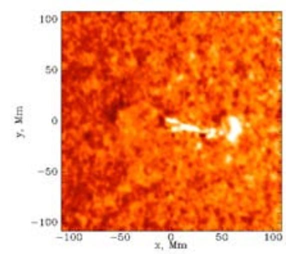
- Transverse
  - Waves on a rope
- Longitudinal (compressional)
  - Sound waves
- Other examples of waves
  - Water waves
  - Seismic waves



## Water waves?

- Water waves occur on the surface. They are a kind of transverse wave.

On Earth

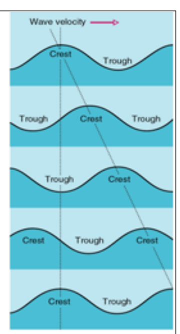


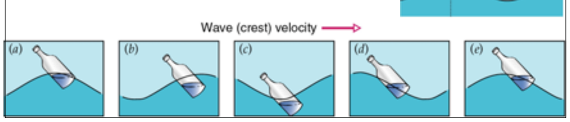

On the sun



## Water's Motion I

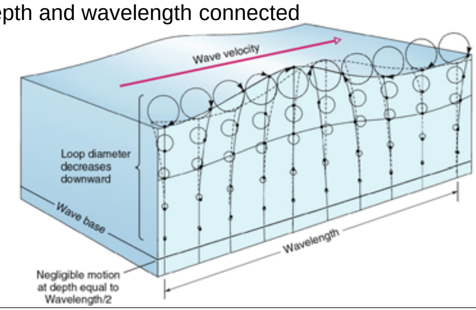
The wave travels while the water circles!




## Water's Motion

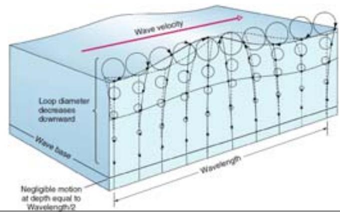
- Circling strongest at surface
- Weak ~ 1/2 wavelength deep
- Depth and wavelength connected



## Wavelength of water wave

- The longer the wavelength of the wave
  – the deeper it goes
  – the more energy it contains for a given amplitude

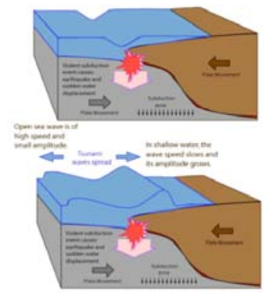
Tsunamis are very long wavelength, very deep, very high energy waves



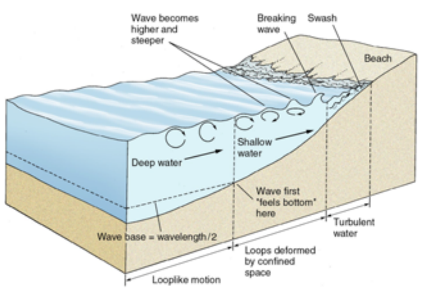



## Tsunamis

- Generate by some disturbance
  - Landslide
  - Undersea earthquake
- Generates long-wavelength propagating water wave







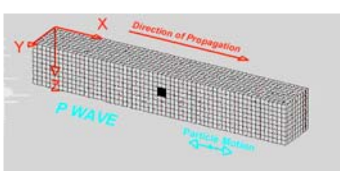

As the wave approaches shallower water, the surface component becomes higher and steeper.

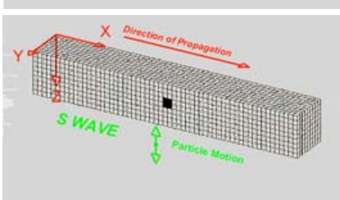


## Tsunami is a wave

- December 26, 2004 tsunami was generated from the 9.0 Richter scale Sumatra earthquake
- Like all waves, tsunami transported energy but not mass.
  - The water that impacted the beaches in Sri Lanka, for example, did not "come from" Sumatra;
  - Just the energy "came from" Sumatra.
- Wavelength, period, and velocity:
  velocity = wavelength × frequency
- Frequency = 1 / period:
  - period of 40 minutes gives frequency of about 0.0004Hz (cycles per second).
  - The wavelength of this tsunami in deep water is about 500km
  - From this we can compute the tsunami velocity to be about 200m/s or 450 miles an hour - about as fast as a jet airplane!






## *Seismic waves*

*Waves in the earth generated by earthquake*

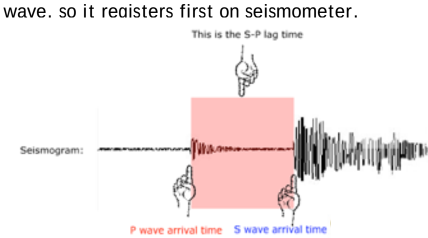
*P* (primary) wave: compressional
$v_P$~ 6 km/s

*S* (secondary) waves: transverse
$v_S$~3.5 km/s



## Detecting with seismometer

- *P* (transverse) wave travels faster than *S* (compressional) wave, so it registers first on seismometer.



## Locating an earthquake

Time difference between *P* arrival time and *S* arrival time due to difference in velocities.

*P* travel time = distance / *P*-velocity

*S* travel time = distance / *S*-velocity

$$\text{Arrival time difference} = (\text{P travel time}) - (\text{S travel time}) = \frac{\text{distance}}{\text{P velocity}} - \frac{\text{distance}}{\text{S velocity}}$$

$$\Delta t = \frac{d}{v_S} - \frac{d}{v_P} = d\left(\frac{1}{v_S} - \frac{1}{v_P}\right) = d(0.119\ \ s/km)$$

$$d = (8.4\ \ km/s)\Delta t$$

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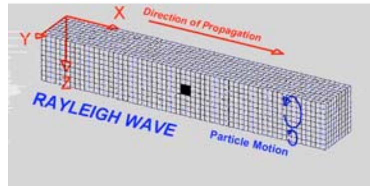
## *Seismic Rayleigh wave (R-wave)*




•Rayleigh wave: another wave from earthquakes
— Particle motion roughly circular.
— Amplitude decreases with depth.
— A 'surface wave'.

*This is same as a water wave!*
*But counterclockwise*

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## Combining waves

- Two traveling waves can meet and pass through each other without being destroyed or even altered
- Waves obey the *Superposition Principle*
  - If two or more traveling waves are moving through a medium, the resulting wave is found by adding together the displacements of the individual waves point by point
  - **Constructive interference**: waves reinforce
  - **Destructive interference:** waves tend to cancel

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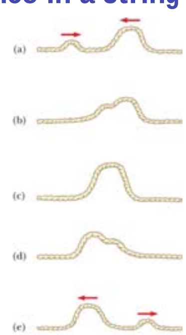
## Constructive Interference in a String

- Two pulses are traveling in opposite directions
- The net displacement when they overlap is the sum of the displacements of the pulses
- Note that the pulses are unchanged after the interference

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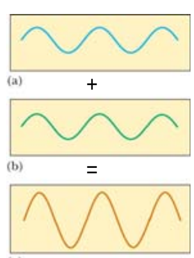
## Constructive Interference

- Two waves, a and b, have the same frequency, amplitude, and start point
  - Are *in phase*
- The combined wave, c, has the same frequency and a greater amplitude

Combined wave

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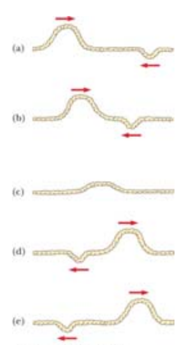
## Destructive Interference in a String

- Two pulses are traveling in opposite directions
- The net displacement when they overlap is the displacements of the pulses subtract
- Note that the pulses are unchanged after the interference

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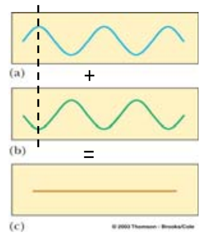
## Destructive interference in a continuous wave

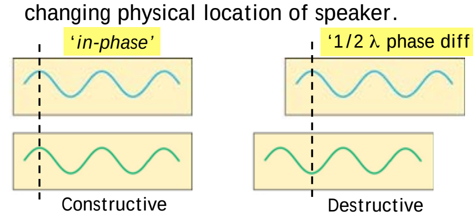
- Two waves, a and b, have the same amplitude and frequency
- They are 1/2 wavelength out of phase
- When they combine, the waveforms cancel






## Interference of sound waves

- Interference arises when waves change their ‘phase relationship’.
- Can vary phase relationship of two waves by changing physical location of speaker.





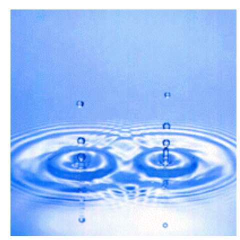

## Example

- Speed of sound ~ 340 m/s
- So $f$=340 Hz gives $\lambda = v/f$ = 1 meter
- Change of 1/2 wavelength is 1/2 meter.
- Or can change phase relationship by changing relative distance from source.



## Interference

- Water drop is a source of circular waves (two-dimensions here)
- When the waves overlap, they superimpose.
- In some areas they cancel, in others they reinforce.
- This is called interference



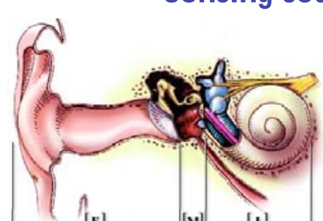


## Sound waves again

- Sound is a compressional wave
- The crest is a local compression of the air, the trough a local rarefraction.
- Can be produced by objects transferring their vibratory motion to the air
  - Tuning fork
  - Speaker
  - Musical instrument



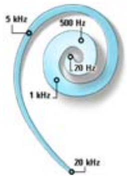
## Sensing sound




Middle ear transmits sound to cochlea, which discriminates loudness and pitch

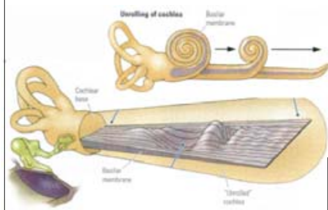
## Discriminating pitch

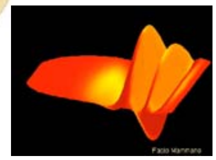
- Your ear detects sound
- A mechanosensitive hair bundle in the cochlea of the ear. Each hair bundle is made up of 30-300 stereocilia (tiny hairs).
- Different locations host bundles that send different pitch signals.






## Vibrations of the basilar membrane







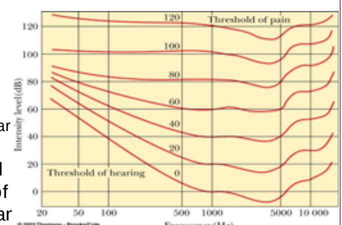
## Pitch

- Pitch is related mainly, although not completely, to the frequency of the sound
- Pitch is not a physical property of the sound
- Frequency is the stimulus and pitch is the response
  - It is a psychological reaction that allows humans to place the sound on a scale



## Frequency Response Curves

- Bottom curve is the threshold of hearing
  - Threshold of hearing is strongly dependent on frequency
  - Easiest frequency to hear about 3000 Hz
- When the sound is loud (top curve, threshold of pain) all frequencies can be heard equally well





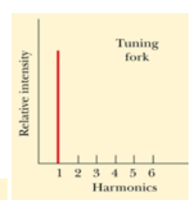

## Timbre

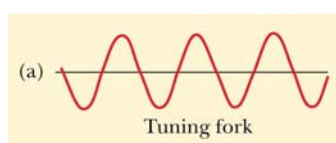
- In music, the characteristic sound of any instrument is referred to as the quality of sound, or the *timbre* of the sound
- Not all sound is a pure tone.
- The quality depends on the mixture of 'harmonics' in the sound.
- This is a mixture of other frequencies with the original.
- Can completely describe the sound by only including 'overtones'



## Quality of Sound – Tuning Fork

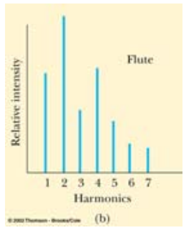
- Tuning fork produces only the fundamental frequency

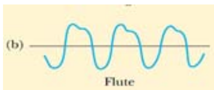


# Quality of Sound – Flute

- The same note played on a flute sounds differently
- Not a pure tone

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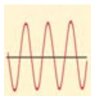

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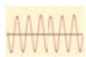

*Fundamental, Freq. f* — *1st harmonic, Freq. 2f* — *2nd harmonic Freq. 3f*



# Quality of Sound – Clarinet

- The fifth harmonic is very strong
- The first and fourth harmonics are very similar, with the third being close to them