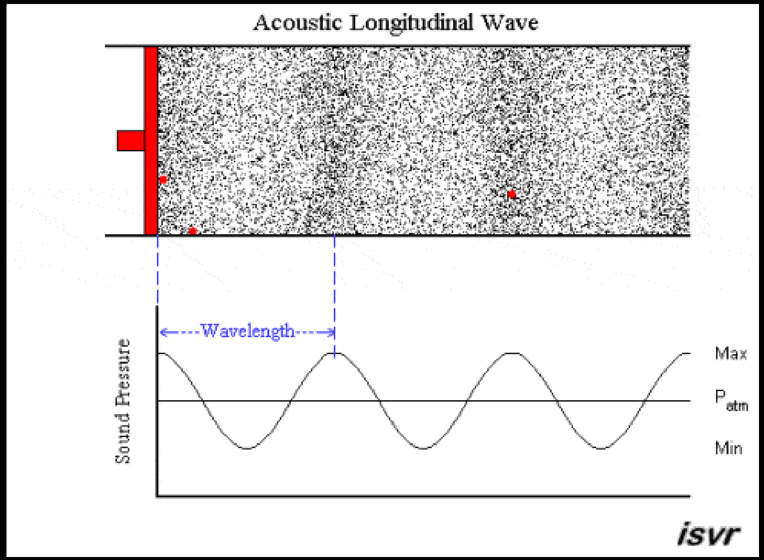
AP Physics

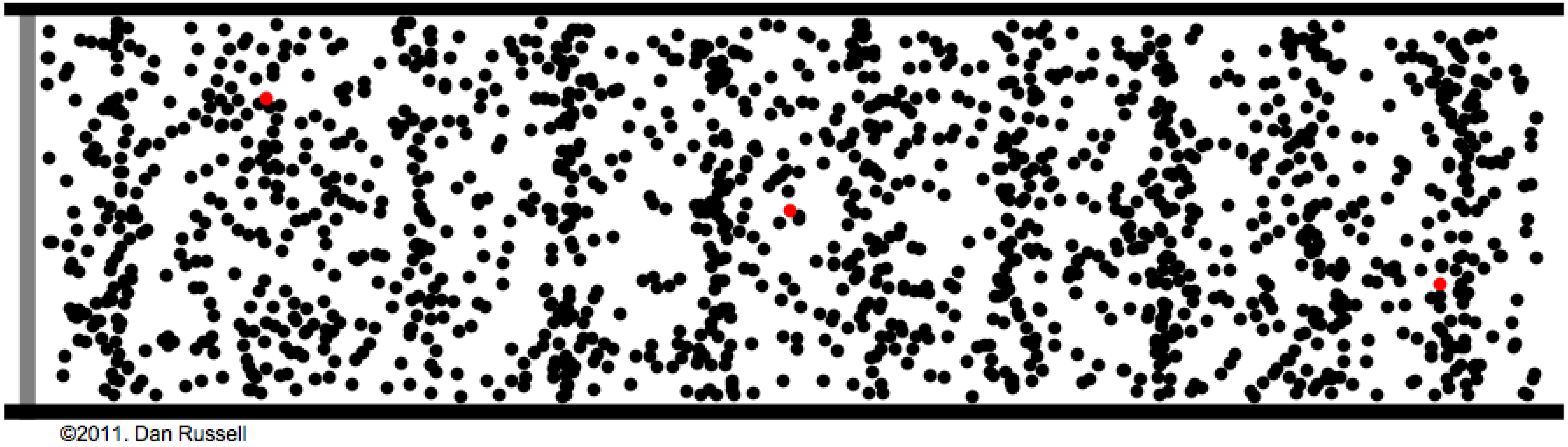
Chapter 14: Sound



What is Sound?

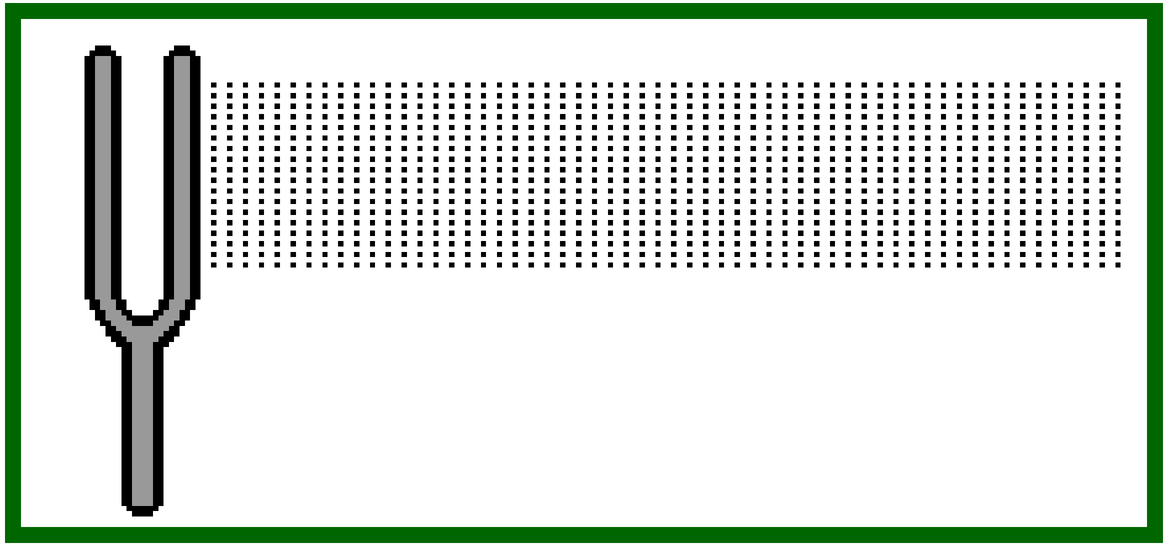
- Sound waves are longitudinal pressure waves.
- Their source comes from a vibrating object that pushes molecules.
- The molecules run into each other and transfer their energy but they themselves do not move in position.
- Sound waves must have a medium to propagate through.

Visual Example of Sound



Another Example of Sound

- A tuning fork is able to produce a sound by vibrating at a specific frequency.
- Each time it vibrates it pushes the air molecules next to it and generates a pressure wave.



Categories of Sound Waves

- **Audible Waves**

  - Lay within the normal range of hearing

  - Normally between 20 Hz to 20,000 Hz

- **Infrasonic Waves**

  - Frequencies below the audible range

  - Earthquakes are a great example

- **Ultrasonic Waves**

  -Frequencies above the audible range

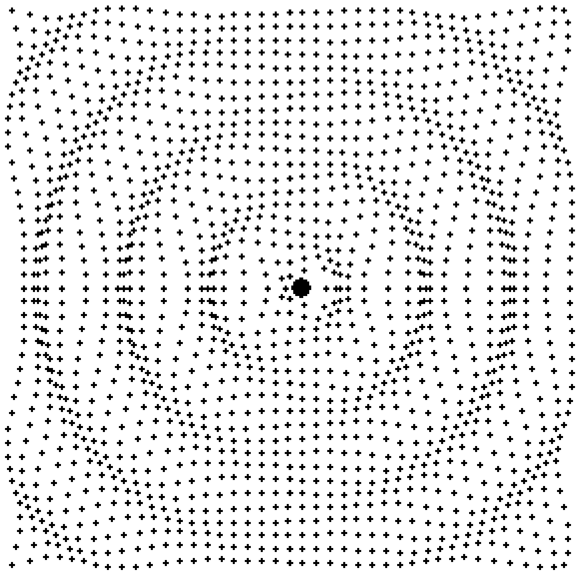
  -Example: Dog Whistles

Applications of Sound Waves

- Can be used to produce images of small objects
- Widely used as a diagnostic and treatment tool in medicine
  - Ultrasonic flow meter to measure blood flow
  - May use *piezoelectric* devices that transform electrical energy into mechanical energy
  - Ultrasounds to observe babies in the womb
  - Cavitron Ultrasonic Surgical Aspirator (CUSA) used to surgically remove brain tumors; High-intensity Focused Ultrasound (HIFU) is also used for brain surgery
- Ultrasonic ranging unit for cameras

Speed of Sound in Air

$$v = \left(331\frac{m}{s}\right)\sqrt{\frac{T}{273\,K}}$$



- 331 m/s is the speed of sound at 0° C (273K)
- Sound travels at different speeds in different temperatures

Speed of Sound in General

$$v = \sqrt{\frac{\text{elastic property}}{\text{inertial property}}}$$

- The speed of sound is higher in solids than in fluids
  - The molecules in a solid are closer together therefore the molecules take less time to transfer their energy from one particle to the other.
- The speed is slower in liquids than in solids
  - Fluids are more compressible and the particles are farther apart, so it takes more time for the particles to transfer their energy.

Speed of Sound in Fluids

- In a fluid, the speed depends on the fluid's compressibility and inertia

$$v = \sqrt{\frac{B}{\rho}}$$

  - B is the Bulk Modulus of the liquid or the resistance to compressibility for that fluid
  - ρ is the density of the liquid
  - Compares with the equation for a transverse wave on a string

Speed of Sound in Solids

- The speed depends on the solid's compressibility and inertial properties

$$v = \sqrt{\frac{Y}{\rho}}$$

  - Y is the Young's Modulus of the material or how well the solid resists compression
  - ρ is the density of the material

Sound Intensity

- The sensation of loudness is logarithmic in the human ear
- β is the intensity level or the decibel level of the sound

$$\beta = 10 \log\left(\frac{I}{I_o}\right)$$

- I_o is the threshold of hearing
- I is usually measured in $\frac{W}{m^2}$

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Intensity vs Intensity Level

- Intensity is a physical quantity with units.

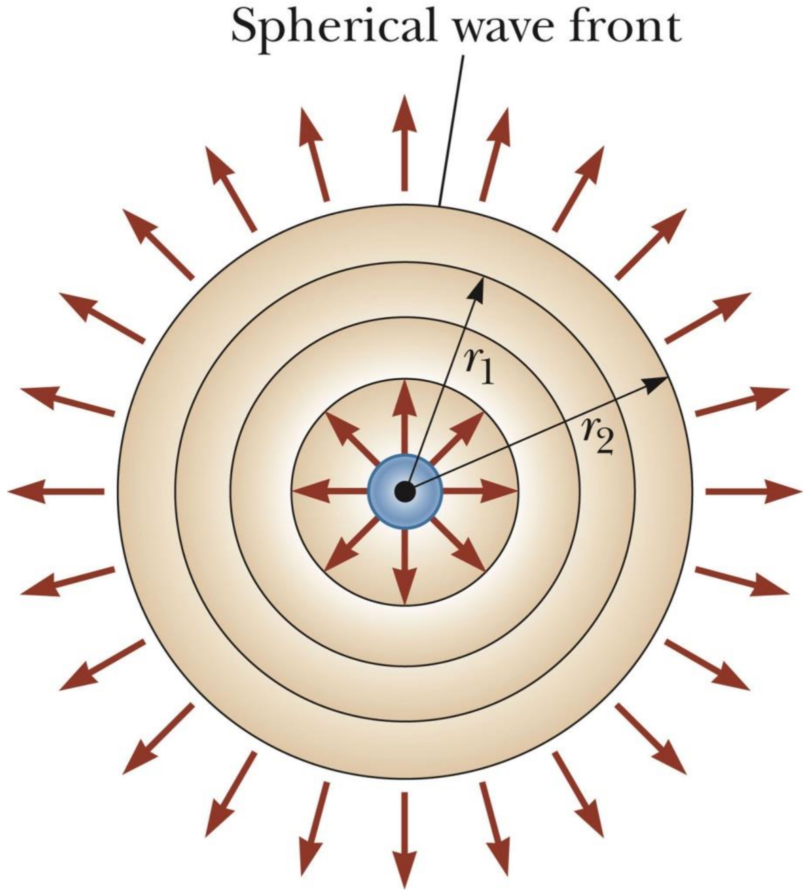
- Intensity level is a unit-less convenient mathematical transformation of intensity to a logarithmic scale

Intensity Levels

- Threshold of hearing is 0 dB
- Threshold of pain is 120 dB
- Jet airplanes are about 150 dB
- Table 14.2 (page 476) lists intensity levels of various sounds
  - Multiplying a given intensity by 10 adds 10 dB to the intensity level

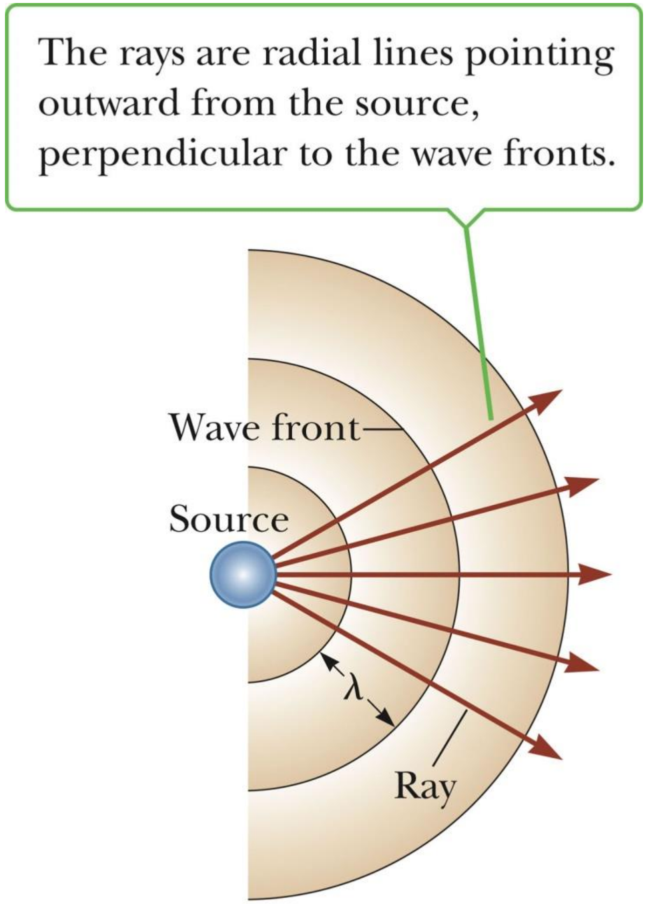
Spherical Waves

- A spherical wave propagates radially outward from the oscillating sphere
- The energy propagates equally in all directions

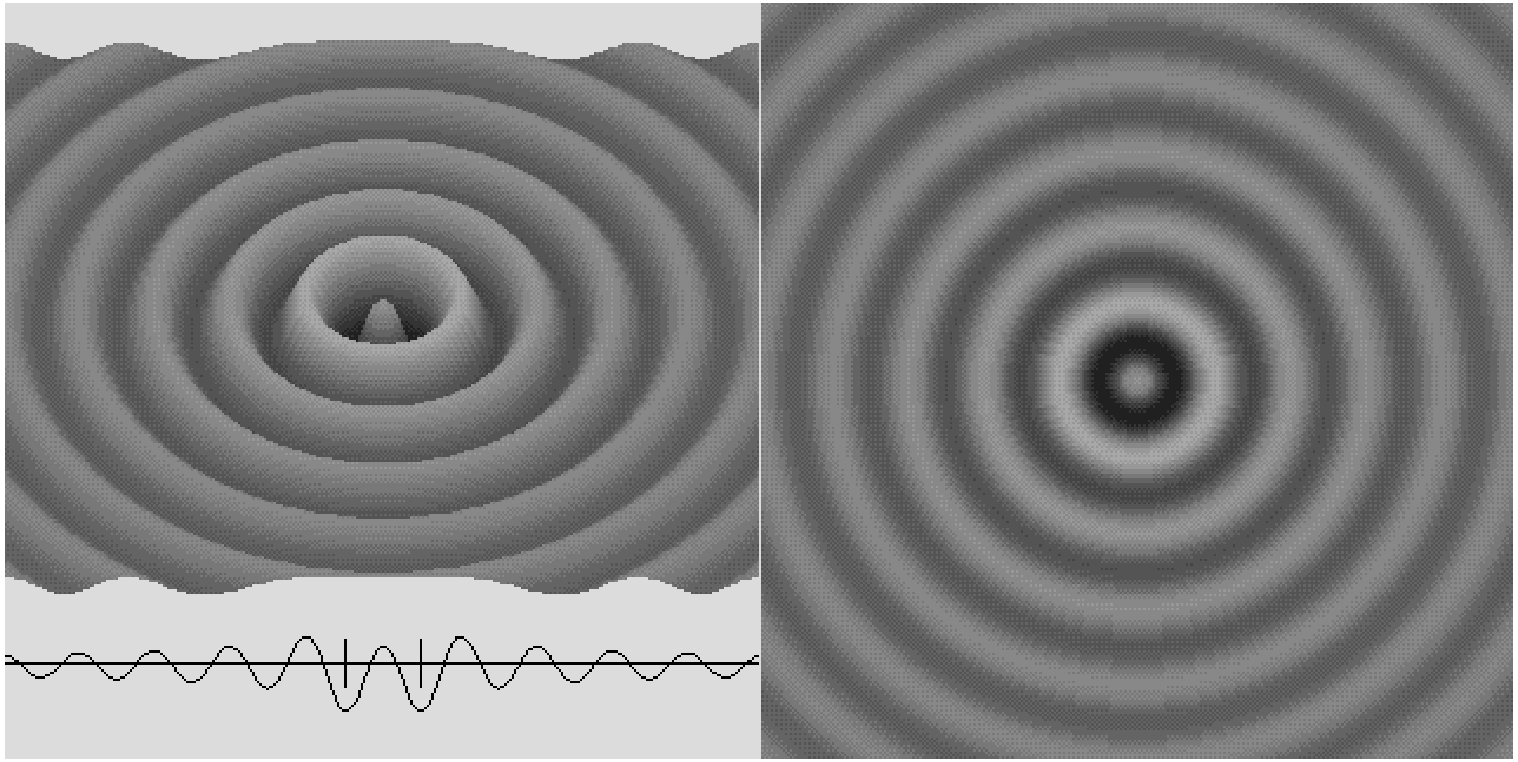


Spherical Waves

- *Wave fronts* are the concentric arcs
  - The distance between successive wave fronts is the wavelength
- *Rays* are the radial lines pointing out from the source and perpendicular to the wave fronts

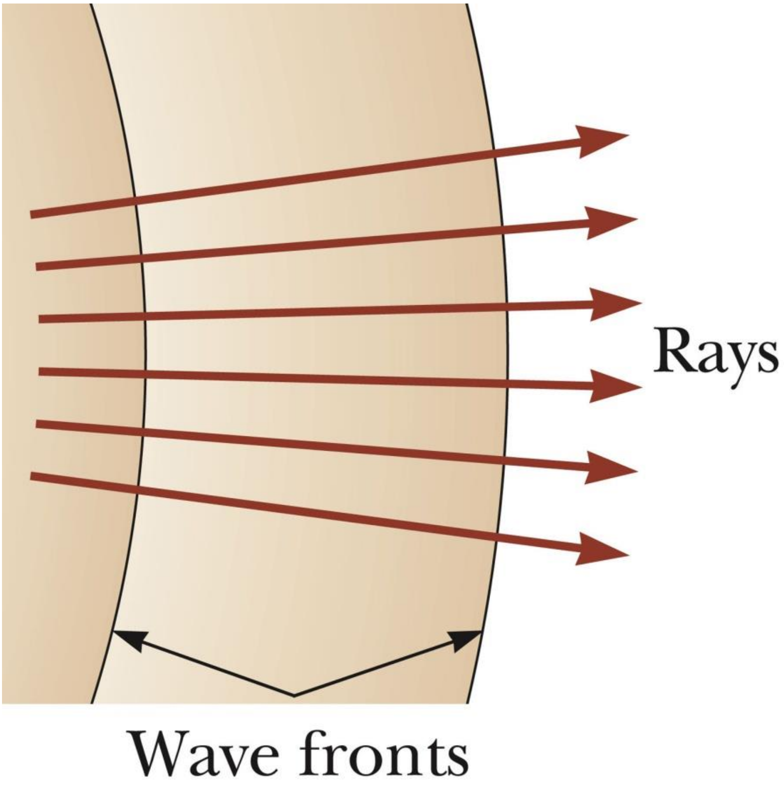


Spherical Waves



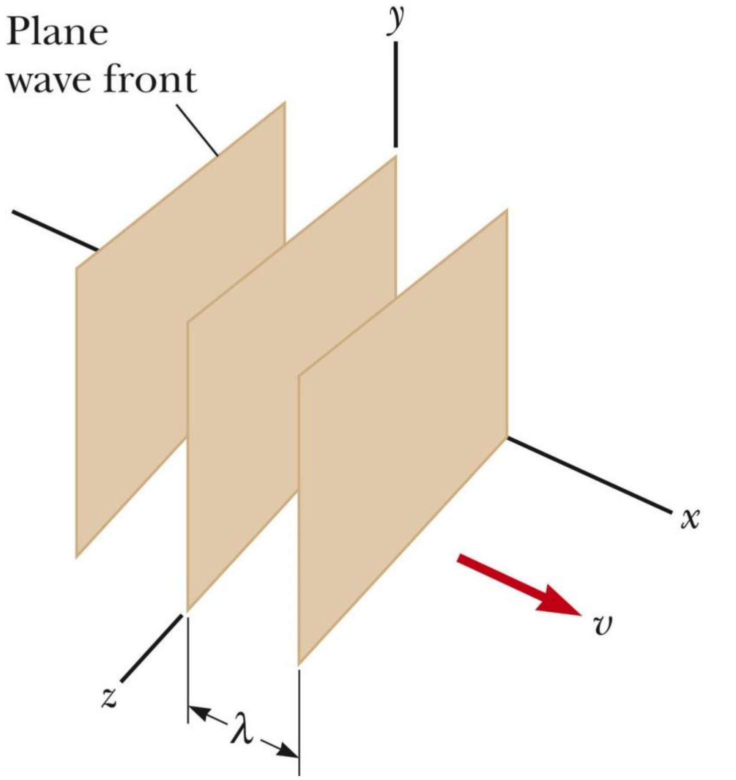
Planar Waves

- Far away from the source, the wave fronts are nearly parallel planes
- The rays are nearly parallel lines
- A small segment of the wave front is approximately a plane wave

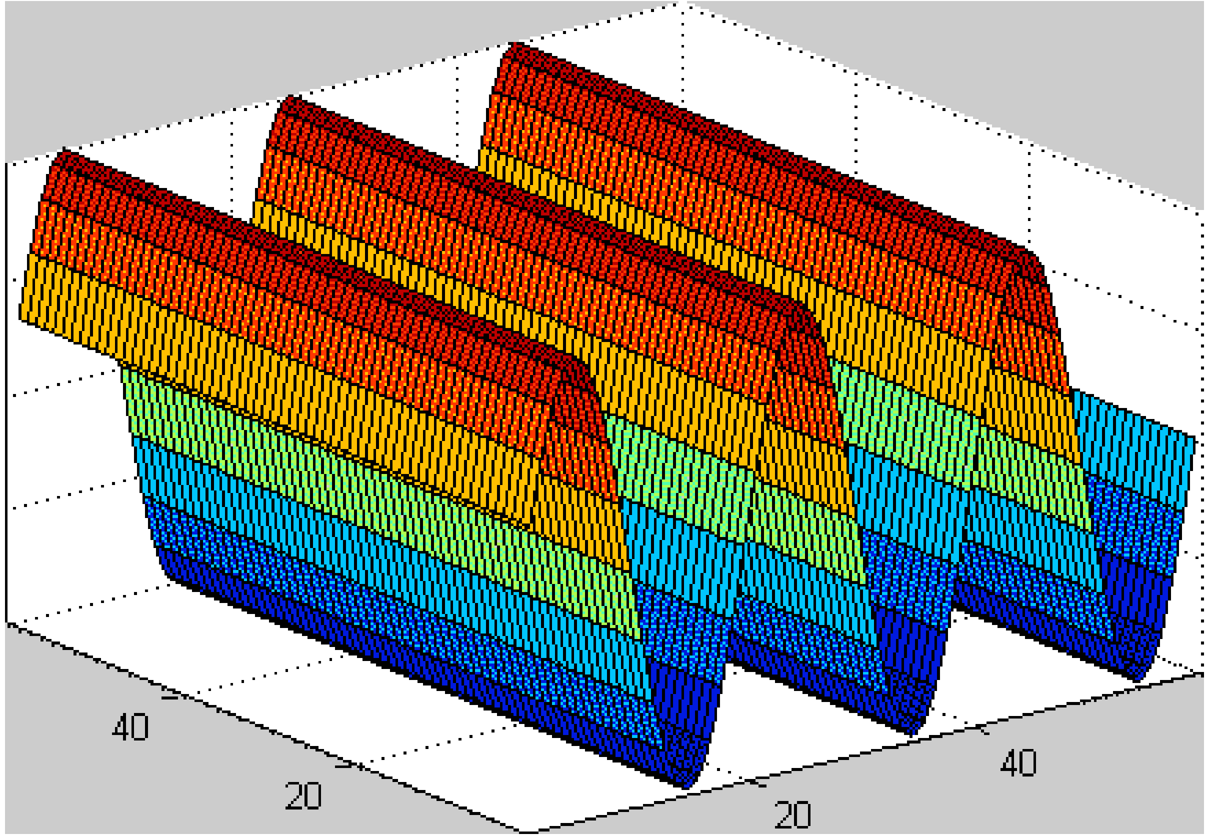


Planar Waves

- Any small portion of a spherical wave that is far from the source can be considered a plane wave
- This shows a plane wave moving in the positive x direction
  - The wave fronts are parallel to the plane containing the y- and z-axes



Planar Waves

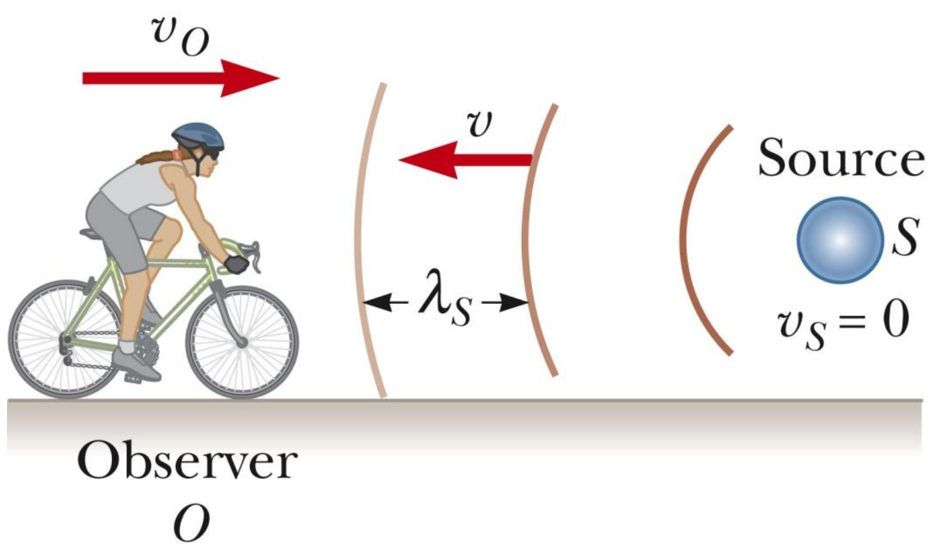


The Doppler Effect

- A phenomena that describes the observed effect of a wave when the observer and or source of the waves are moving.
- This effect applies to all waves.
- When the observer and or the source are moving towards each other the observed frequency of the wave is higher
- When the observer and or the source are moving away from each other the observed frequency of the wave is lower.

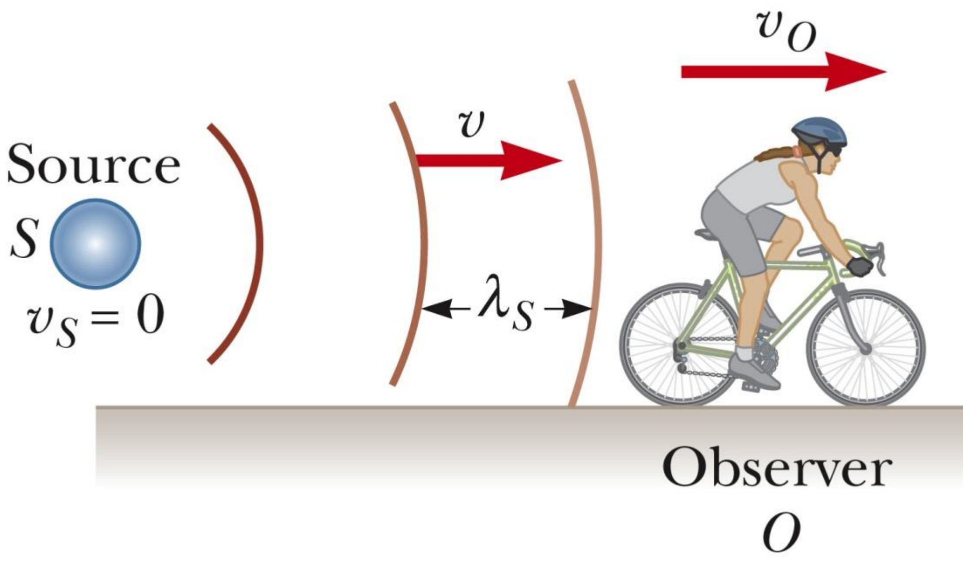
The Doppler Effect

- An observer is moving toward a stationary source
- Due to his movement, the observer detects an additional number of wave fronts
- The frequency heard is increased; the loudness does not change.



The Doppler Effect

- An observer is moving away from a stationary source
- The observer detects fewer wave fronts per second
- The frequency appears lower; the loudness does not change.

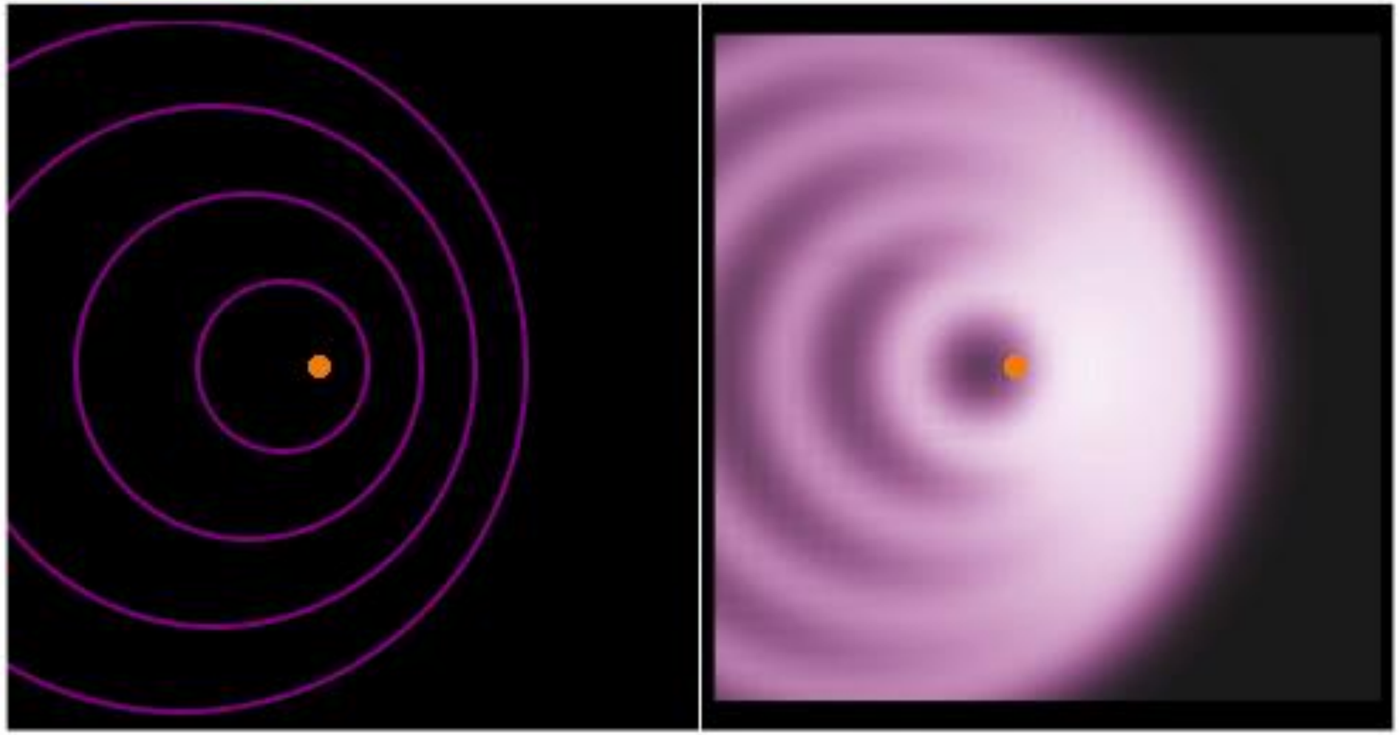


The Doppler Effect

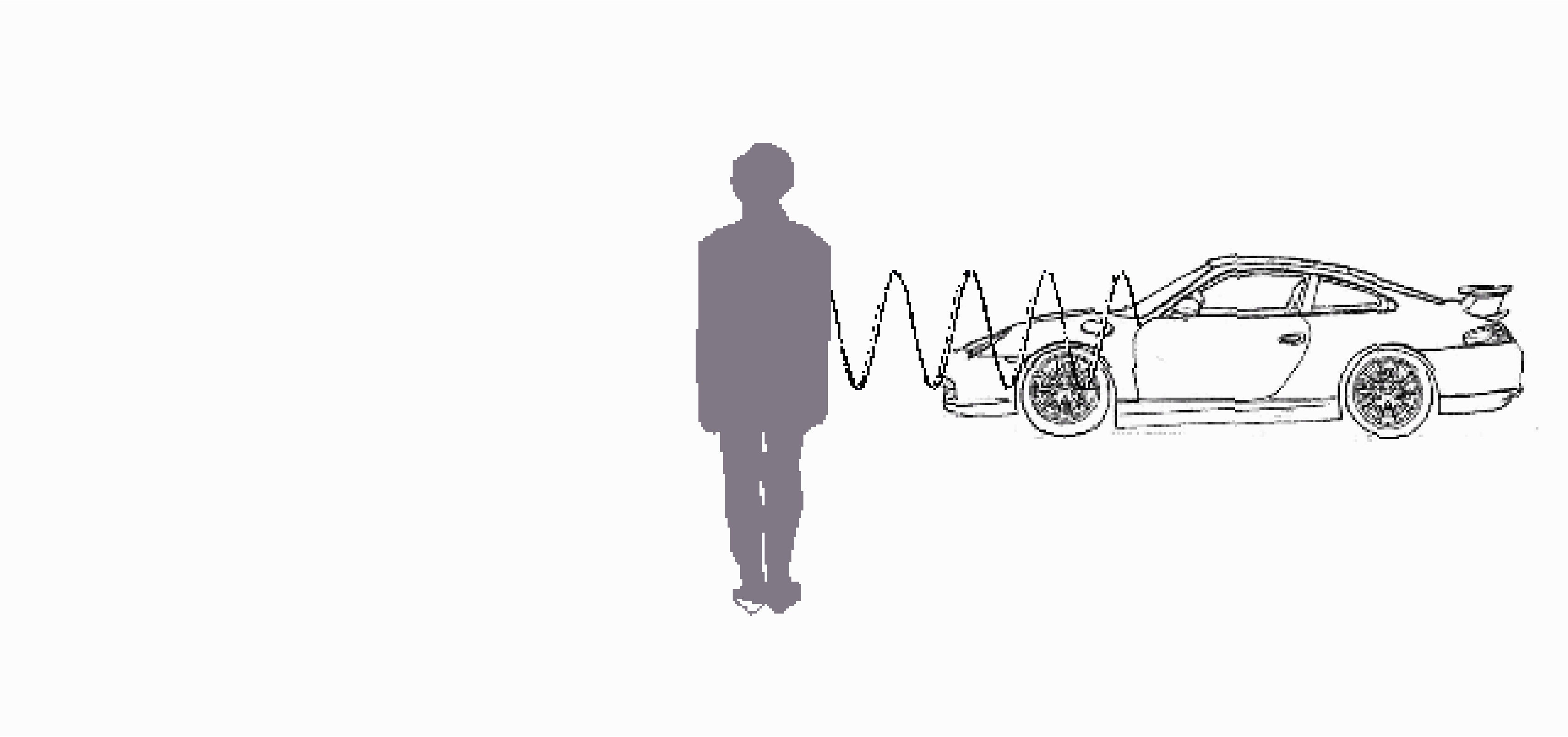
- The Doppler Effect does not depend on distance.
  - As you get closer, the intensity will increase
  - The real frequency will not change
  - The apparent frequency will change

The Doppler Effect Examples

$v_{source} = 0.4 * v_{sound}$



The Doppler Effect Examples



The Doppler Effect Examples

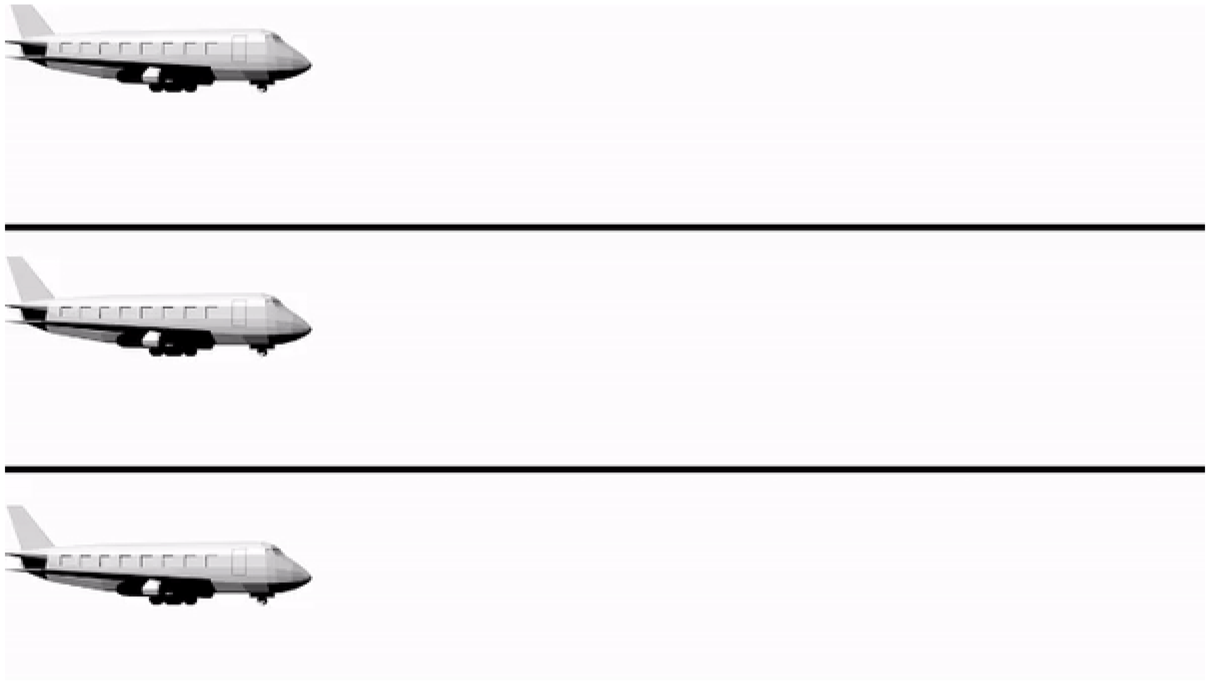
The Doppler Effect Examples

Shock Waves

- What happens when the source of our waves is faster than the waves themselves?

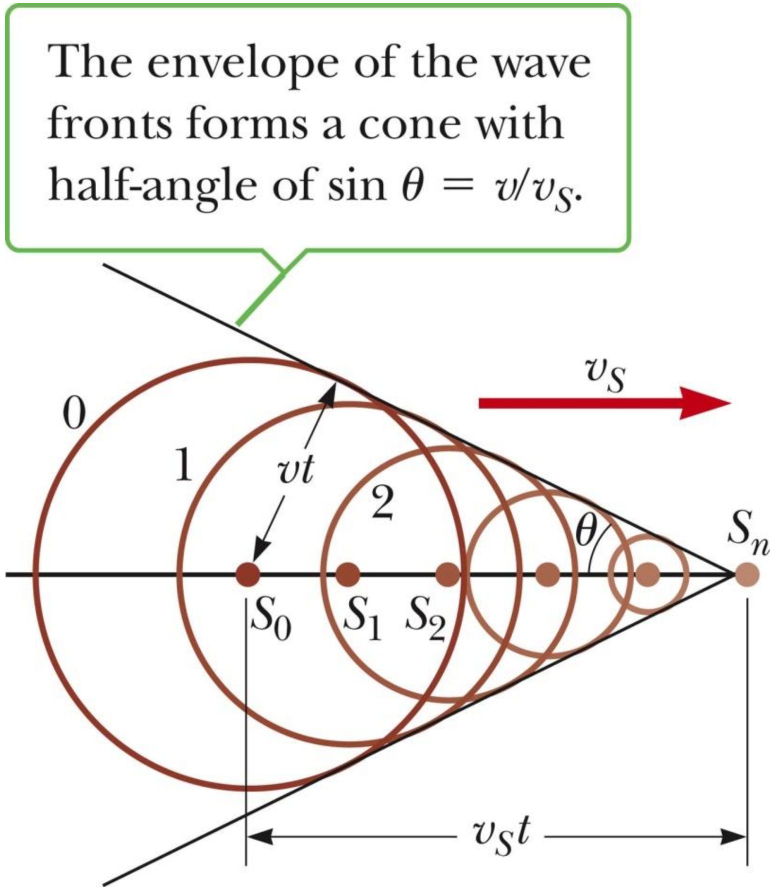
- Sonic Boom! Or a shock wave.

Shock Waves



Shock Waves

- A shock wave results when the source velocity exceeds the speed of the wave itself
- The circles represent the wave fronts emitted by the source



Shock Waves

- Tangent lines are drawn from S_n to the wave front centered on S_o
- The angle between one of these tangent lines and the direction of travel is given by $\sin \theta = v / v_s$
- The ratio v_s / v is called the *Mach Number*
- The conical wave front is the *shock wave*

Shock Waves

- Shock waves carry energy concentrated on the surface of the cone, with correspondingly great pressure variations
- A jet produces a shock wave seen as a fog of water vapor

Shock Waves

Interference of Waves

- Sound waves interfere
  - Constructive interference occurs
    when the path difference between two waves' motion is zero or some integer multiple of wavelengths
    - Path difference = $n\lambda$ ($n = 0, 1, 2, \ldots$)
  - Destructive interference occurs when the path difference between two waves' motion is an odd half wavelength
    - Path difference = $(n + \frac{1}{2})\lambda$ ($n = 0, 1, 2, \ldots$)

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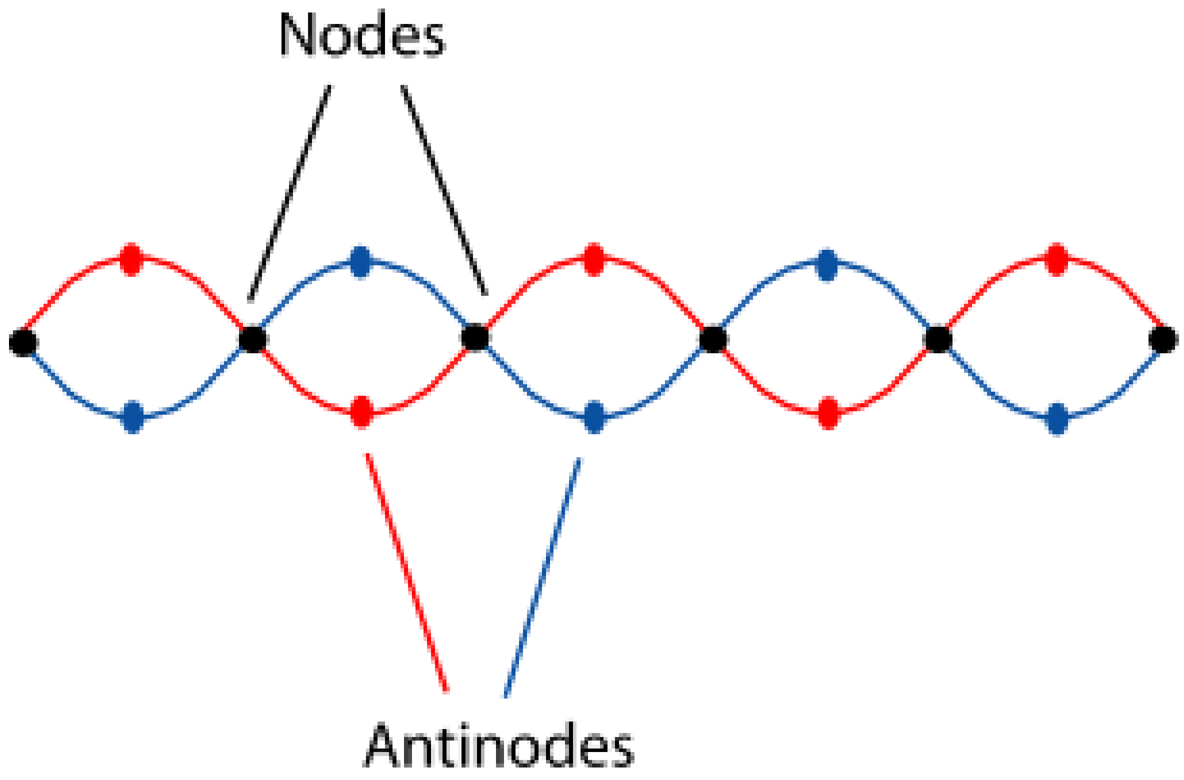
Standing Waves: The only thing that matters

- Whenever a wave is confined to a boundary a standing wave is formed.
- This can be a physical boundary such as a guitar string bound by it’s length or a drum membrane bound by it’s circumference.
- This can also be a boundary in space when a reflected wave travels back on itself or when two identical waves travel in the opposite direction from each other and combine by the superposition principle
- When this happens the wave appears to be motionless, hence the name standing wave.

Standing Waves

- A *node* occurs where the two traveling waves have the same magnitude of displacement, but the displacements are in opposite directions
  - Net displacement is zero at that point
  - The distance between two nodes is ½λ
- An *antinode* occurs where the standing wave vibrates at maximum amplitude

Standing Waves



Standing Waves

- Standing waves have defined wavelengths based on the length of their boundary

$$\lambda = \frac{2}{n} L$$

Where

- λ = wavelength
- L = length of boundary
- n = an increasing integer starting at 1

Standing Waves

- Let’s talk about a guitar string.
- When you pluck a guitar string you hear a beautiful tone.
- This tone is actually just a superposition of the standing waves that the guitar string can actually make.

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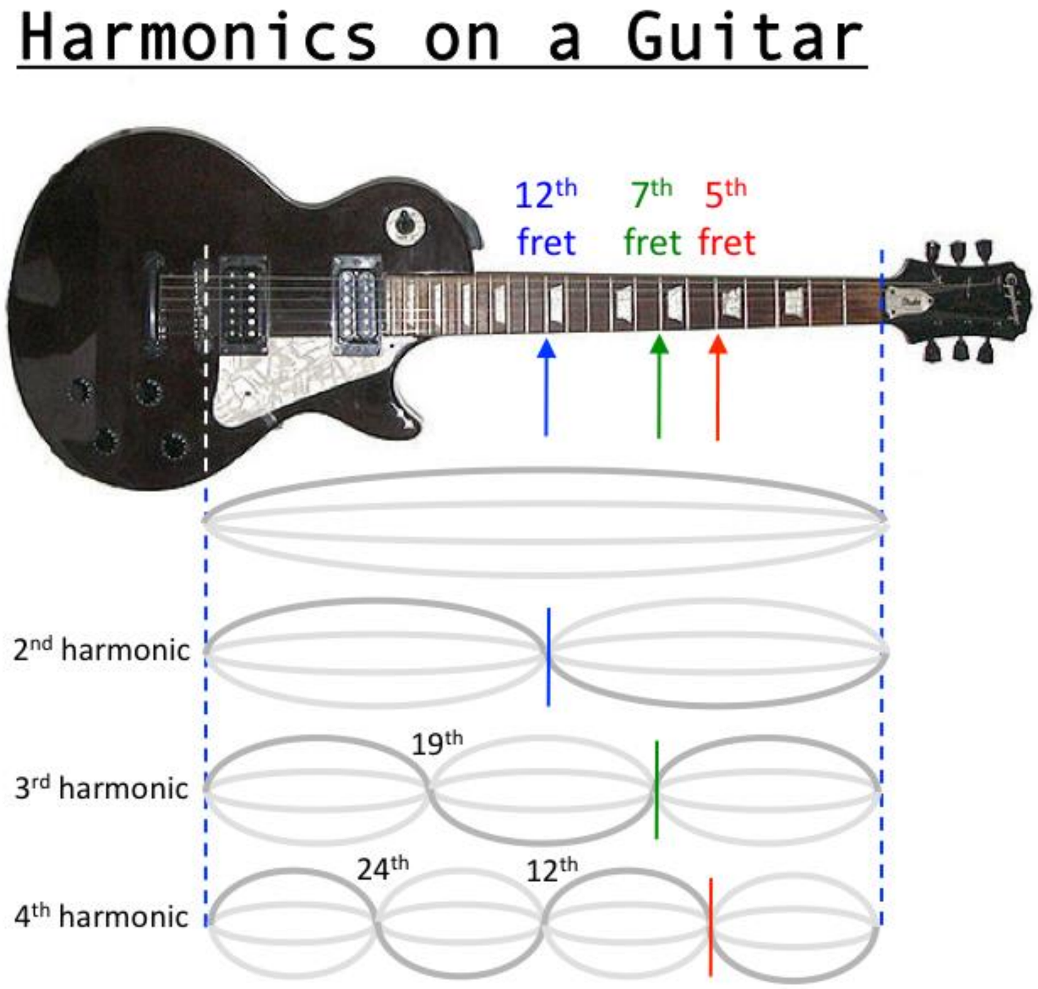
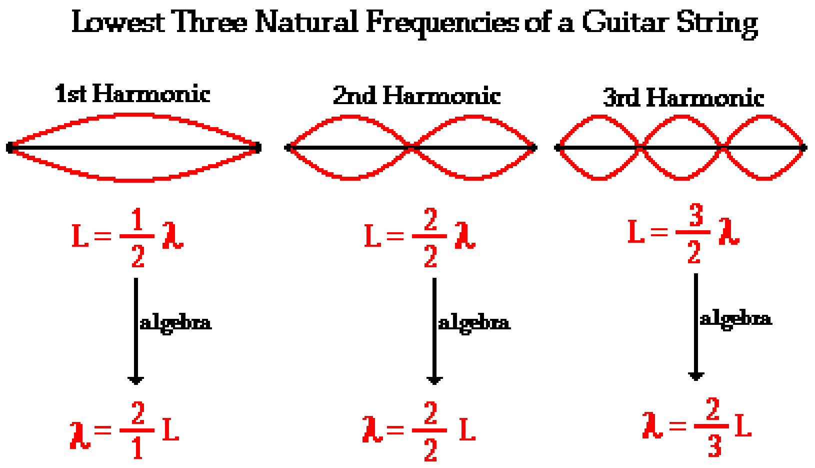


Standing Waves



- f_1, f_2, f_3 form a harmonic series
  - f_1 is the fundamental and also the first harmonic
  - f_2 is the second harmonic or the first overtone
- Waves in the string that are not in the harmonic series are quickly damped out
  - In effect, when the string is disturbed, it “selects” the standing wave frequencies

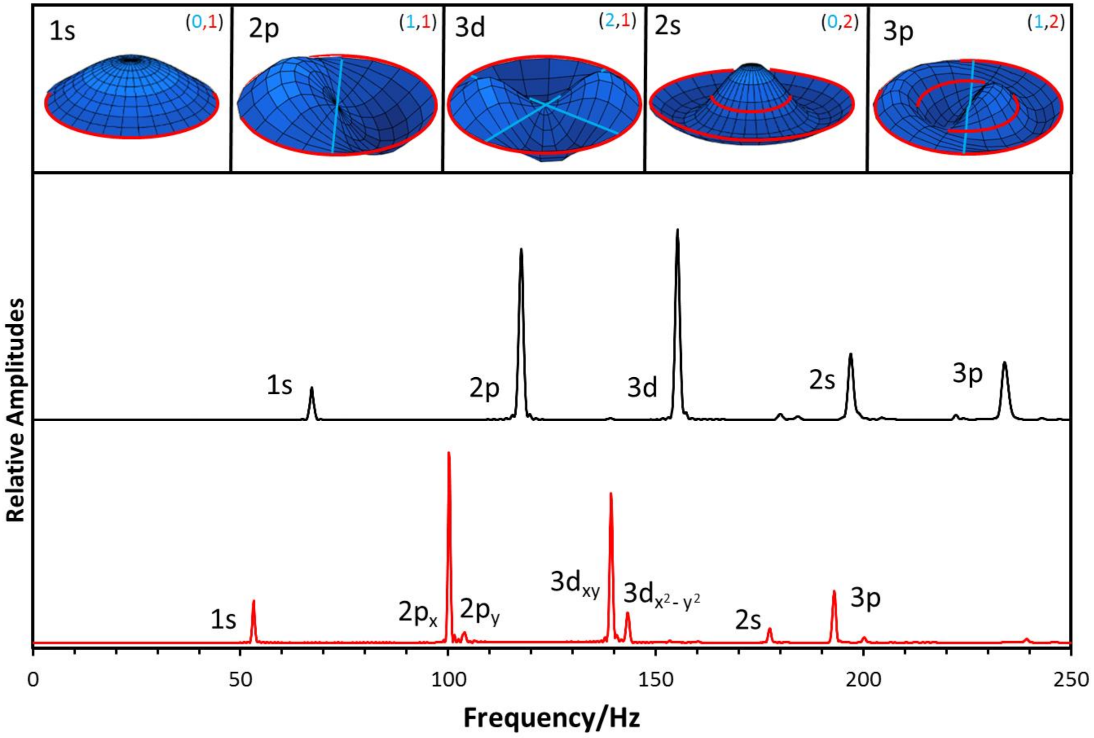
Standing Waves

- These harmonic frequencies are said to the be the natural frequencies of the object in question. However, these natural frequencies behave differently.

- Some harmonics will have different intensities than other harmonics and the time in which these harmonics decay also varies.

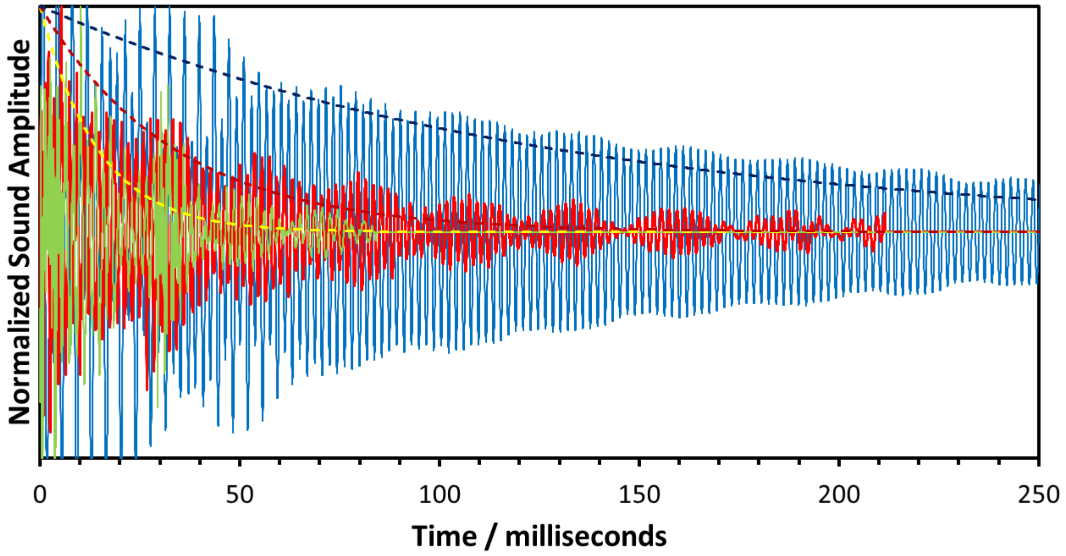
Standing Waves

- The natural frequencies for a drum head.

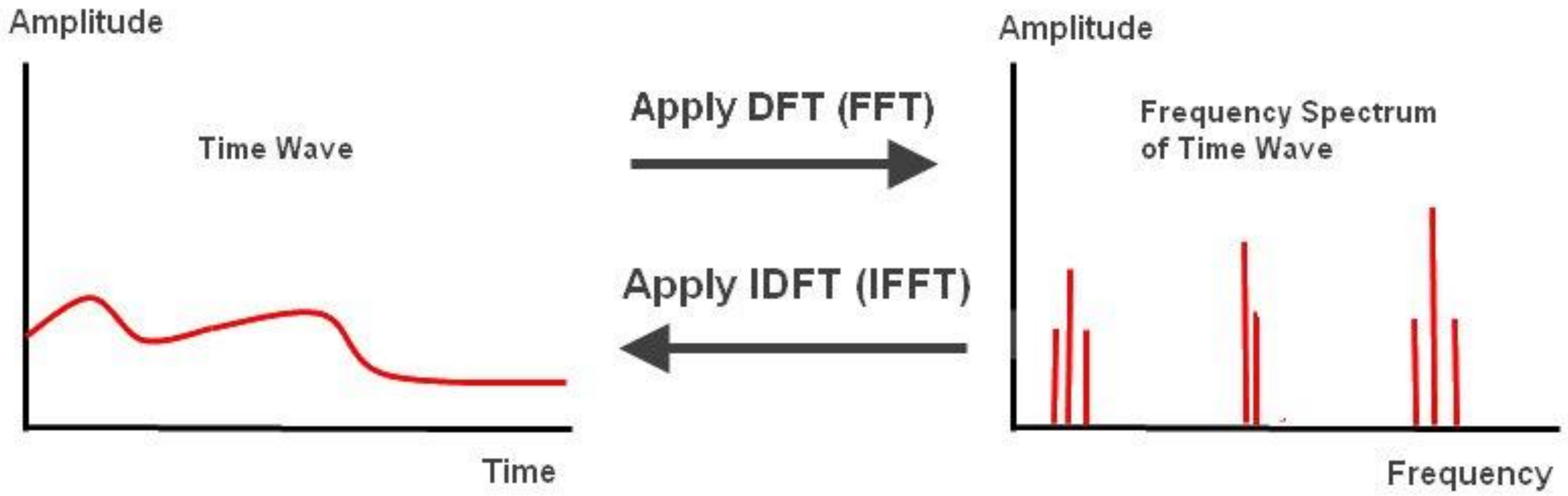


Analyzing Real Waves

- If we record the sound of let's say a drum head when it is hit we can analyze the sound and break it up into it's natural harmonics that make the wave using a Fourier Transform to transfer the recorded sound out of the time domain into the frequency domain.

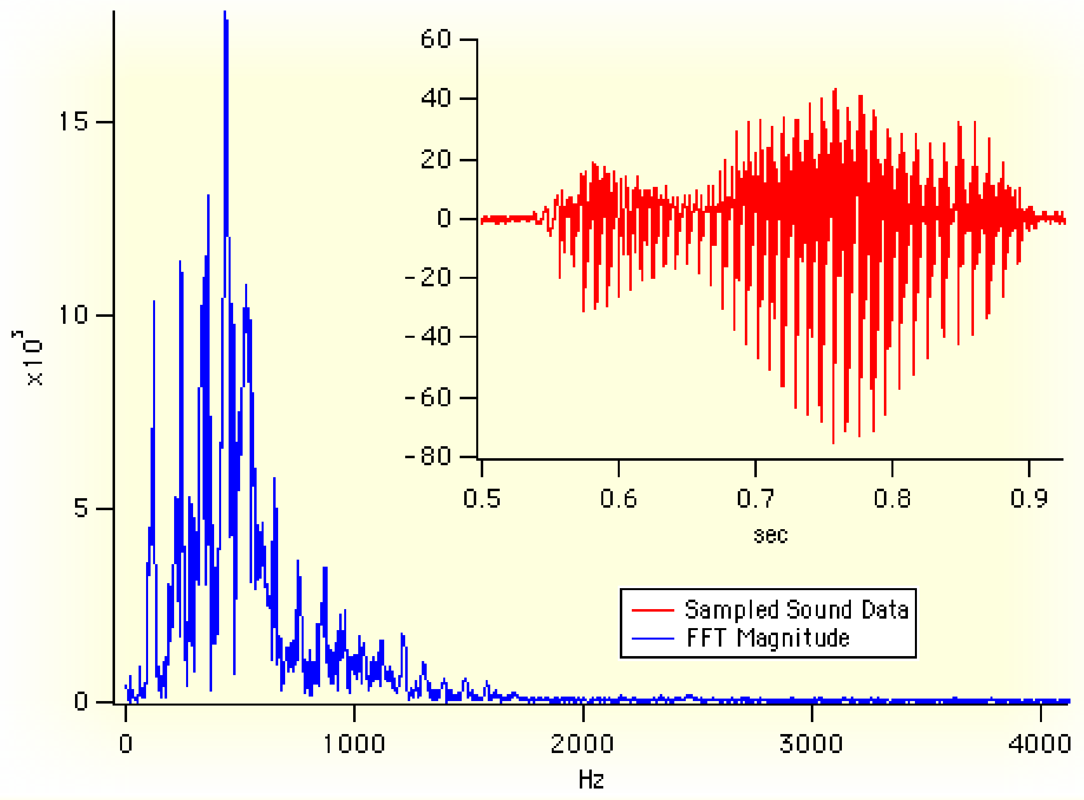


Analyzing Real Waves



Analyzing Real Waves

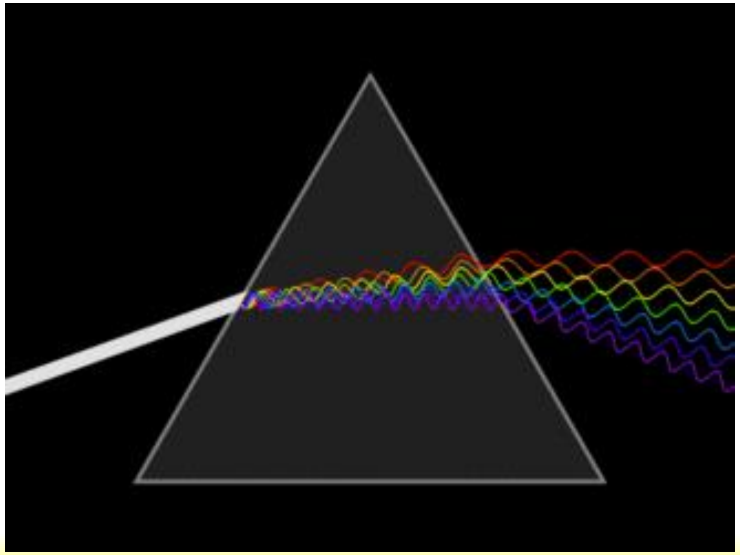
- What most sound Fourier Transforms look like.



Analyzing Real Waves

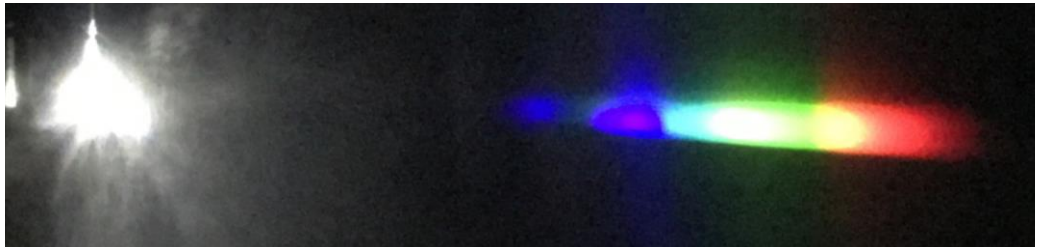
- Sound is not the only wave that abides by the superposition principle though

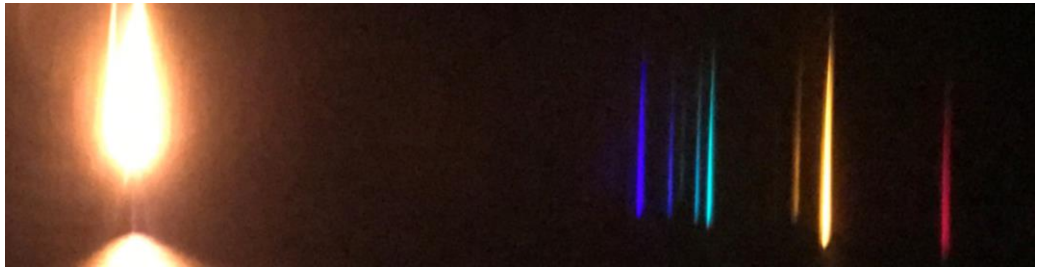
- White light is an example of a superposition of all the wavelengths of visible light.



Analyzing Real Waves

- This also lends us the ability to identify atoms based off of their emission spectrum because the frequency of the waves relates to the energy levels of their atomic orbitals



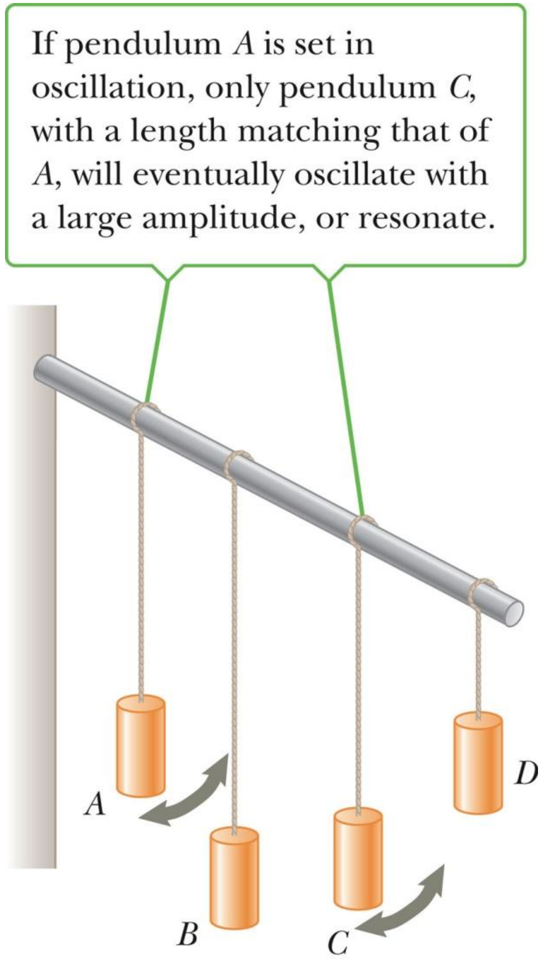


Analyzing Real Waves

- Once we understand the natural frequencies of an object though we can play those same frequencies back at the object to excite it.

- This leads us to the idea of **resonance.**

Resonance



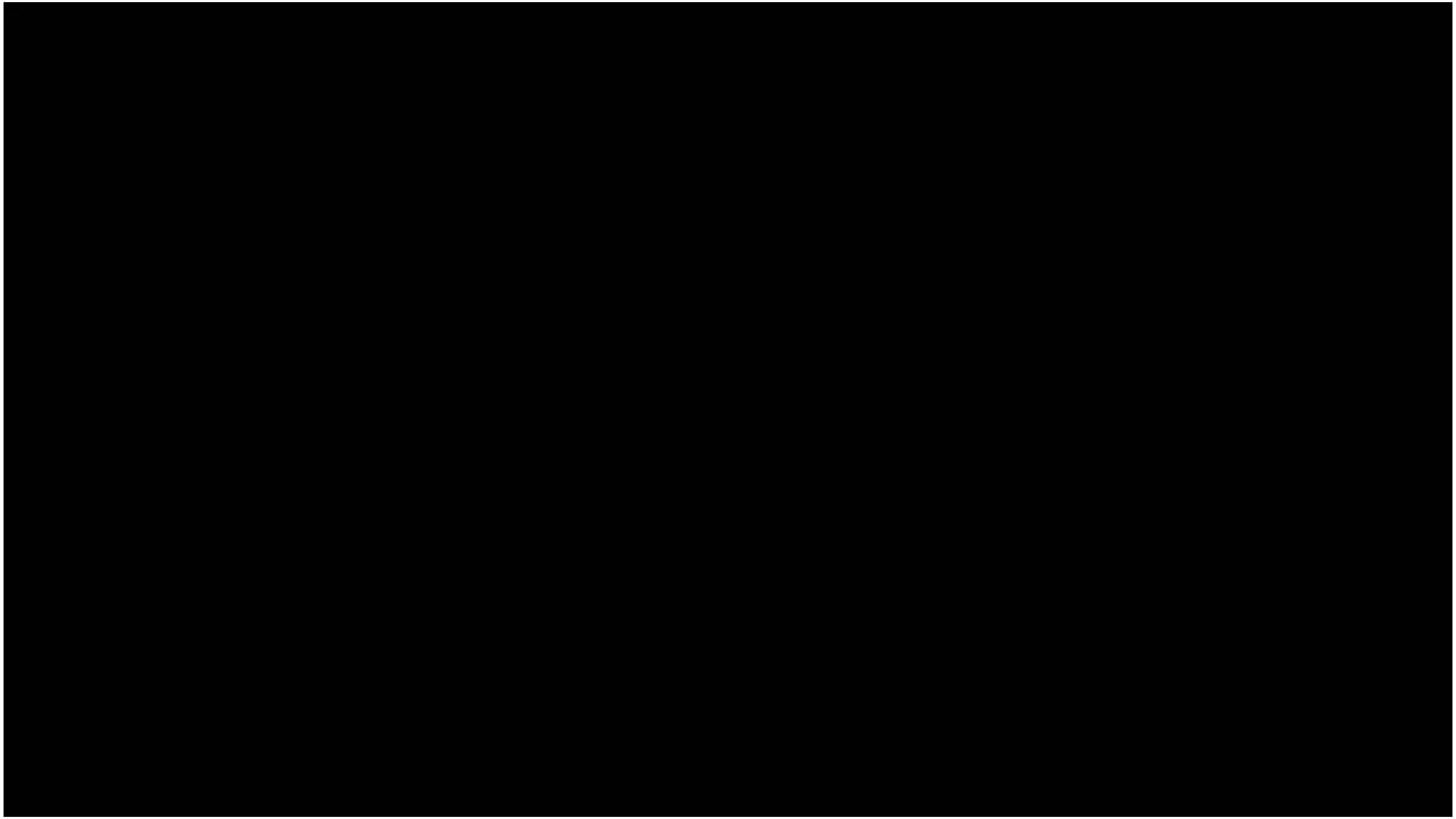
- Pendulum A is set in motion
- The others begin to vibrate due to the vibrations in the flexible beam
- Pendulum C oscillates at the greatest amplitude since its length, and therefore its natural frequency, matches that of A

Resonance

- Child being pushed on a swing
- Shattering a wine glass
- Upper deck of the Nimitz Freeway collapse due to the Loma Prieta earthquake
- Tacoma Narrows Bridge collapse due to oscillations caused by the wind
- Exciting a drum head by playing it’s natural frequencies at it
- So many more examples

Resonance

Resonance



Resonance

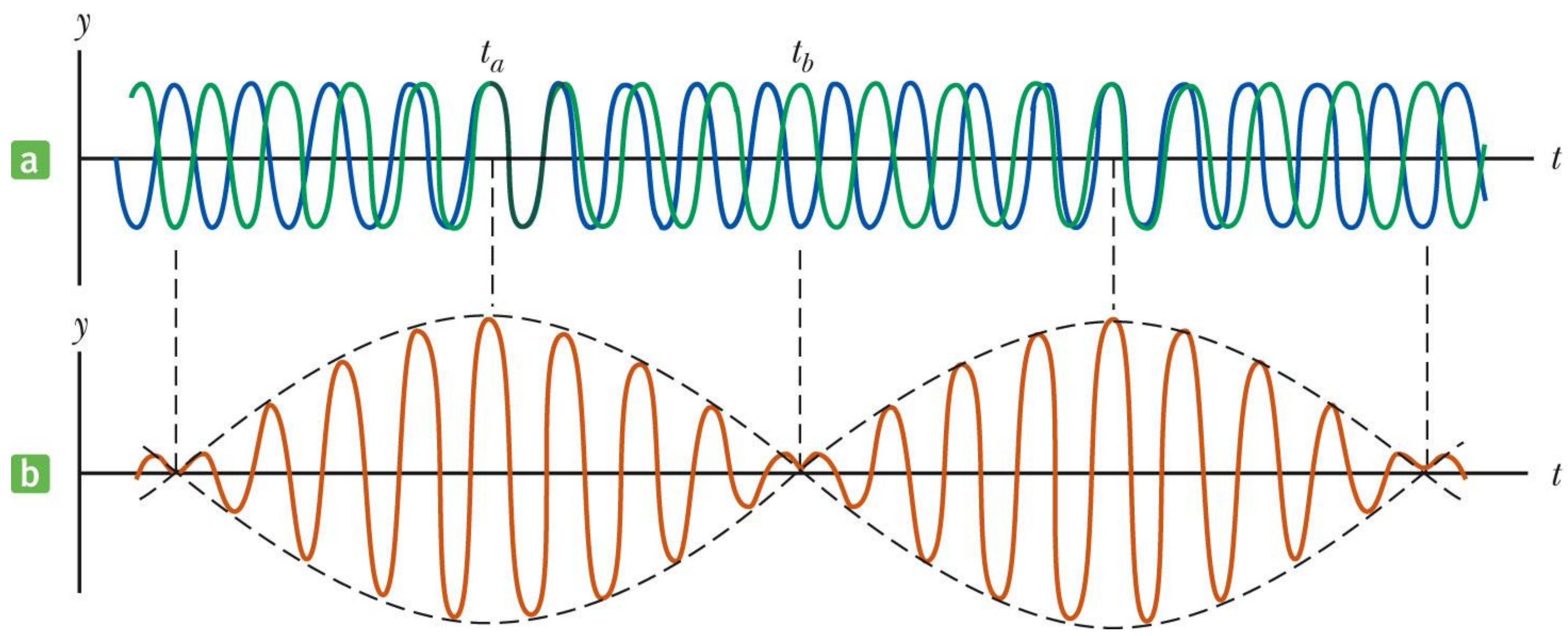
https://www.youtube.com/watch?v=cPALfz-6pnQ

Beats

- Beats are alternations in loudness, due to interference
- Waves have slightly different frequencies and the time between constructive and destructive interference alternates
- The beat frequency equals the difference in frequency between the two sources:

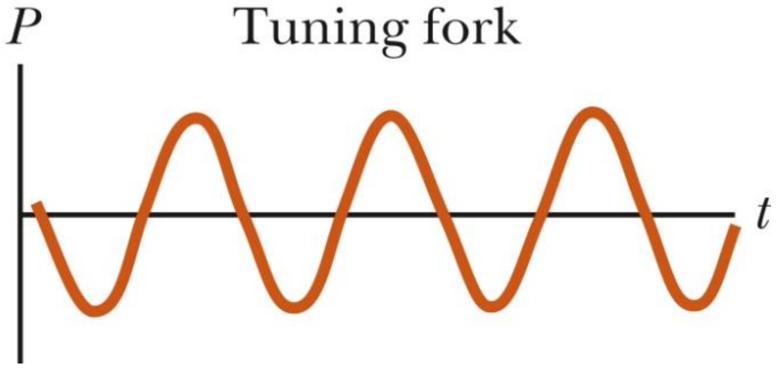
$$f_b = |f_2 - f_1|$$

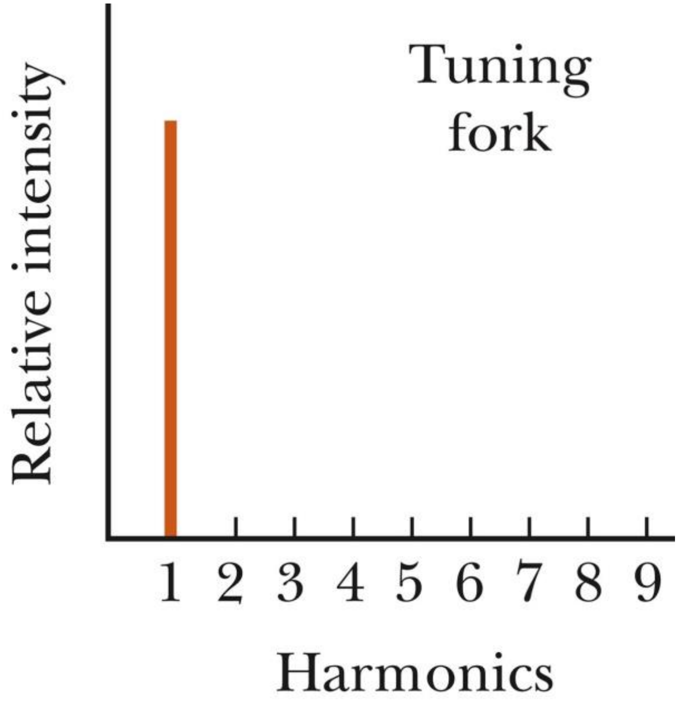
Beats



Quality of sound – Tuning Fork

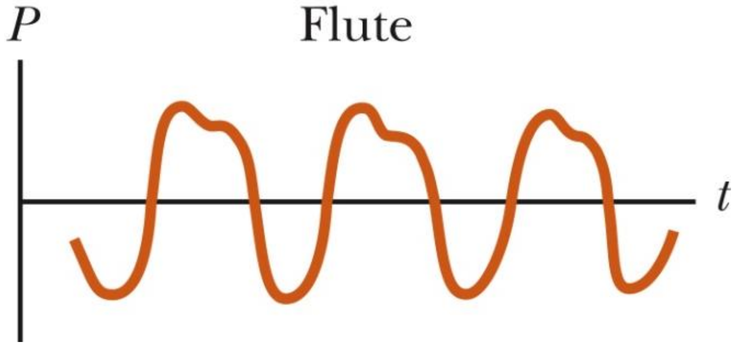
- Tuning fork produces only the fundamental frequency

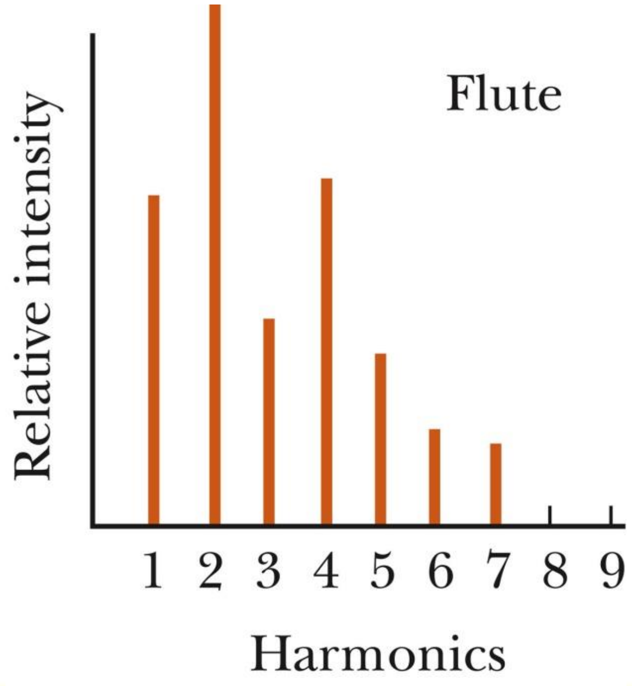




Quality of sound - Flute

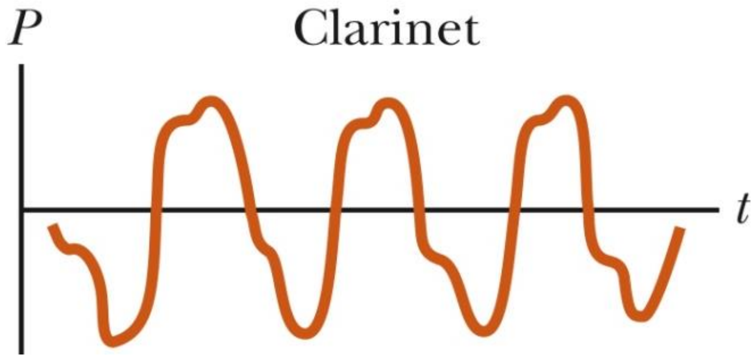
- The same note played on a flute sounds differently
- The second harmonic is very strong
- The fourth harmonic is close in strength to the first

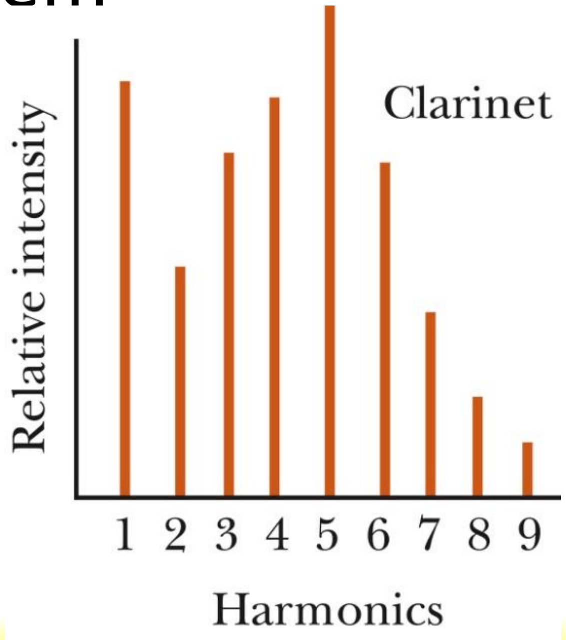




Quality of sound - Clarinet

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





<u>Quality of sound - Timbre</u>

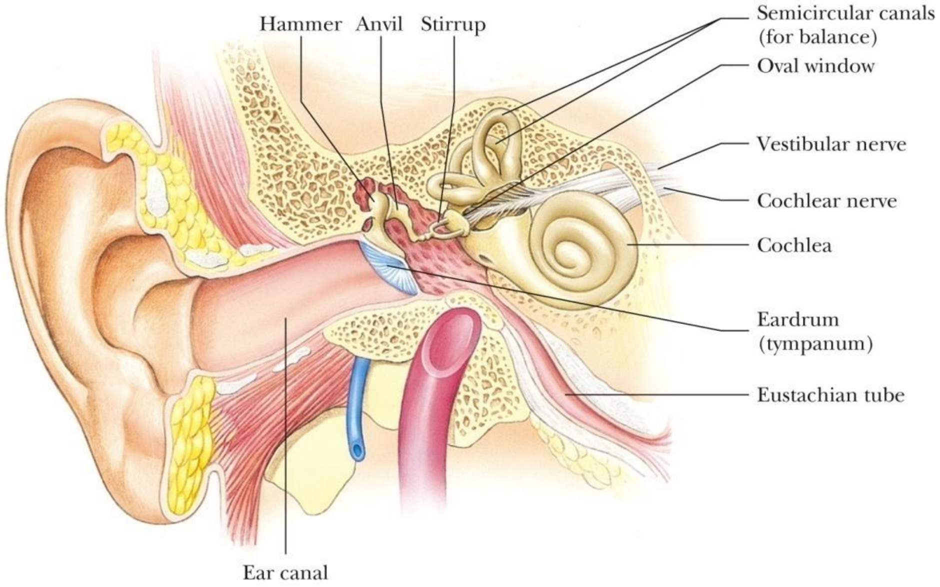
- In music, the characteristic sound of any instrument is referred to as the quality of sound, or the *timbre,* of the sound
- The quality depends on the mixture of harmonics in the sound

Quality of sound - 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

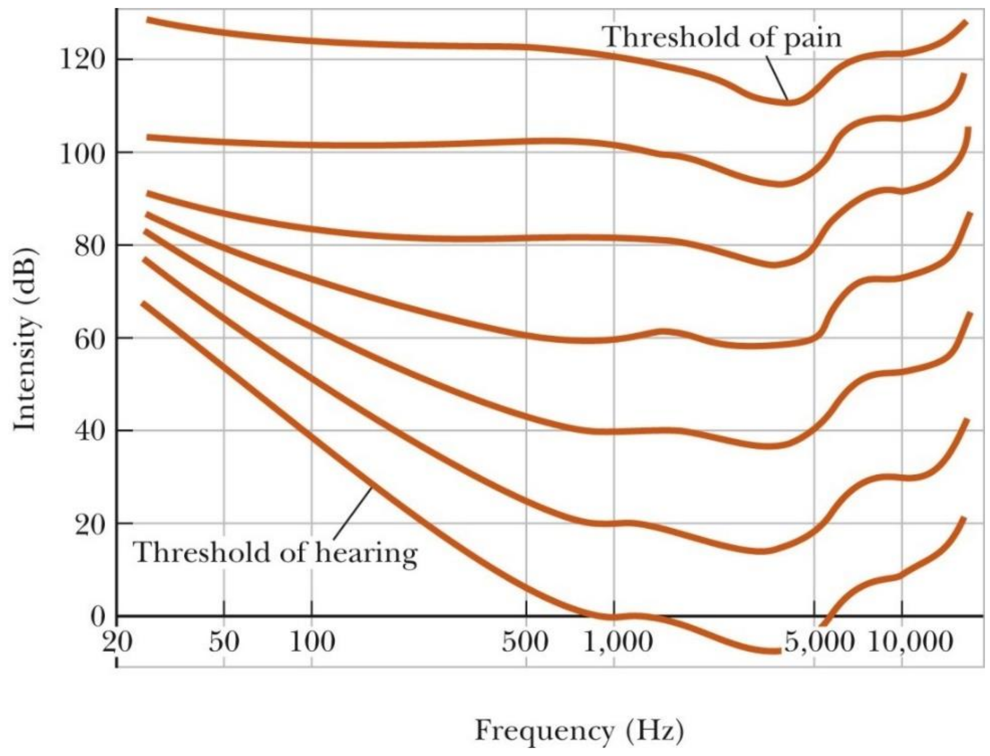
Quality of sound – Human Ear

- The outer ear consists of the ear canal that terminates at the eardrum
- Just behind the eardrum is the middle ear
- The bones in the middle ear transmit sounds to the inner ear



Quality of sound – Hearing

- Bottom curve is the threshold of hearing
  - Threshold of hearing is strongly dependent on frequency
  - Easiest frequency to hear is about 3300 Hz
- When the sound is loud (top curve, threshold of pain) all frequencies can be heard equally well



AP Physics

Chapter 14: Sound

HW: Pg 488 - 494
Conceptual Questions: 1 – 8, 10, 11
Problems: 1,5