Waves at a Boundary

- Gentle boundaries include:
  - Speaker enclosure into open air
  - From water into air (or the reverse)
  - From inside a musical instrument to outside
  - From outside an eyeball to inside
  - From one layer of the atmosphere to the next

Waves at a Boundary

- Two things happen when a wave encounters a new medium:
  - The wave’s speed may change
    - Wave speed depends upon the medium
  - The wave may partially reflect back into the original medium

Wave Speed at a Boundary

- A wave’s speed is related to its frequency and wavelength:
  \[ v = f \lambda \]

- If a wave’s speed changes at a boundary:
  - Then either the frequency and/or the wavelength must change

Wave Speed at a Boundary

- It can be determined experimentally that a wave’s frequency:
  - Does not change at a boundary!

Wave Speed at a Boundary

- Since a wave is an oscillating disturbance in a medium:
  - The rate of oscillations of one medium (their frequency) cause the identical rate in another medium
  - The media are in contact with each other

Wave Speed at a Boundary

- A "middle C" note played by a piano still sounds like a "middle C" note (262 Hz)
  - If heard through a wall
- A green light beam (6 x 10^14 Hz) still looks green
  - If seen through a window
  - Or underwater

Wave Speed at a Boundary

- Since the wave frequency doesn’t change:
  - The wavelength must if the speed is to change

- The change in speed of a wave at a boundary leads to a phenomenon called refraction:
  - Refraction is the change in direction of a wave when it enters a new medium
  - We’ll return to refraction later...
Wave Reflection at a Boundary

- When a wave hits a gentle boundary
  - some of the wave energy will be transmitted into the new medium
  - and some will be reflected back
- This reflected energy will create a standing wave in the original medium
  - This effect can be good or bad...

Wave Reflection at a Boundary

- Good
  - You need a standing wave (created from the reflected energy) to produce sound in a musical instrument
  - The transmitted energy is what “leaks” out and is what we actually hear

Wave Reflection at a Boundary

- Bad
  - Reflected electrical wave energy from the speaker terminals on a stereo back into the stereo’s electronics
  - This is called impedance mismatch and results in wasted energy and annoying ringing in the sound created

Model of a Musical Instrument

- Maximum energy transfer happens when the electrical wave hits a minimal boundary mismatch at the speaker
  - This is called impedance matching

Model of a Musical Instrument

- Maximum energy transfer out of a musical instrument
  - would require the instrument be impedance matched with the surrounding air
  - This is easy to accomplish...
  - For example, the end bell on a trumpet could be flared gently outward so the sound waves would slowly fan out and not be reflected

Model of a Musical Instrument

- This, however well it would transfer sound energy out of the trumpet,
  - would result in no sound at all
  - The sound we hear is from standing waves within the trumpet pipe
  - If there are no wave reflections from the bell end
    - there is no standing wave to produce the sound!!!

Model of a Musical Instrument

- So in order to produce sound
  - musical instruments must have some reflections to create standing waves

Resonance

- Another effect of impedance mismatch and the resulting reflections is the phenomenon of resonance
- Resonance is the sympathetic vibration of a nearby object
  - An object vibrates at the same frequency as the wave it is immersed in

Resonance

- Resonance can be considered to be a matching in frequency
  - between a source of vibrations and a responding system
  - The vibrations produced in a system provide feedback to the source locking them into synchronicity and amplifying the vibrations
    - sometimes disastrously!
Resonance

• Every object has at least one natural resonance frequency
  – It depends upon the material, the size, the shape, etc…

• Most objects have several resonant frequencies
  – although one usually dominates the others

Examples of Resonance

• Example #1: Child on a swing
  – Push at the proper frequency and the child goes higher and higher
  – Otherwise, little or nothing happens

Examples of Resonance

• Example #2: Wind induced oscillations
  – Tacoma Narrows Bridge
  – 11 am 11/07/1940

Examples of Resonance

• Example #3: Magnetic Resonance Imaging (MRI)
  – Radio waves induce oscillations in protons in the body which emit electromagnetic radiation
  – A hydrogen atom (proton) precesses about a magnetic field.

Examples of Resonance

• Example #4: Radio station tuning
  – Radio waves have different frequencies
  – When you tune a radio receiver to a specific station, you are forcing an electrical circuit into resonance with the radio wave
  – and hence forcing a large electrical response
  – This large response overwhelms the other radio waves
  – and allows you to hear just your chosen station!
Resonance

- We can use this effect to determine the resonant frequency of any system!

Resonant Frequency

- Driving Frequency
- Amplitude of response

- Resonant Frequency
- Maximum response
- Building response

This is known as a “sharp” resonance.

- If we now immerse the system in a “sticky” fluid, the system’s response to the driving wave changes substantially…

- The system’s response is now much broader and less specific

- Resonance
- A system with this kind of sharp response is called a lightly damped system
- A system with this kind of broad response is called a heavily damped system

- Another way to view a sharp versus a broad response
- – is by plotting the oscillations as a function of time
- – for one particular driving frequency

- Sharp - Lightly Damped
- Broad - Heavily Damped

- Tim e
- Displacement

- Undamped
- Sharp - Lightly Damped
- Broad - Heavily Damped

Example of Sharp Resonance

- (Lightly Damped)
- The breaking of a wine glass by sound wave resonance

Resonance

- The sharp (lightly damped) resonance system oscillates a large number of times before dying out
- The broad (heavily damped) resonance system only oscillates once or twice before dying out
- Note that the previous figure was a fixed position picture of the waves

- These damping effects are used to great effect in a piano

Resonance

- A sharp resonant response is useful for electronic circuit tuning
  – Such as for a radio receiver
- A broad resonant response is useful for automobile shocks
  – That way the springs respond evenly to all types of road conditions and don’t go wildly out of control for a certain size pot-hole!

- The sharp (lightly damped) resonance system oscillates a large number of times before dying out
- The broad (heavily damped) resonance system only oscillates once or twice before dying out
- Note that the previous figure was a fixed position picture of the waves
Resonance

- A piano has damping pads on each key whose purpose is to make each note played last only about a second. This prevents "old" notes from interfering with "new" ones.

- These damping pads are always in use unless the sustain pedal is held down, which holds the pads away from the strings allowing the note to last several seconds for added effect.