Physics of Sound and Music

Damping, Resonance, Beats, and Harmony

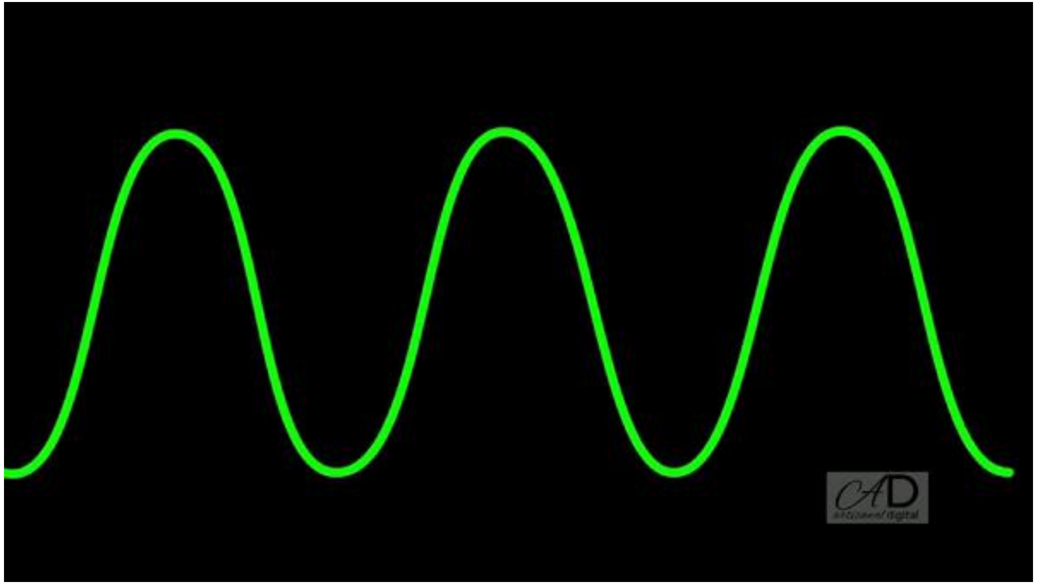
Objectives

By the end of this class, you will be able to….

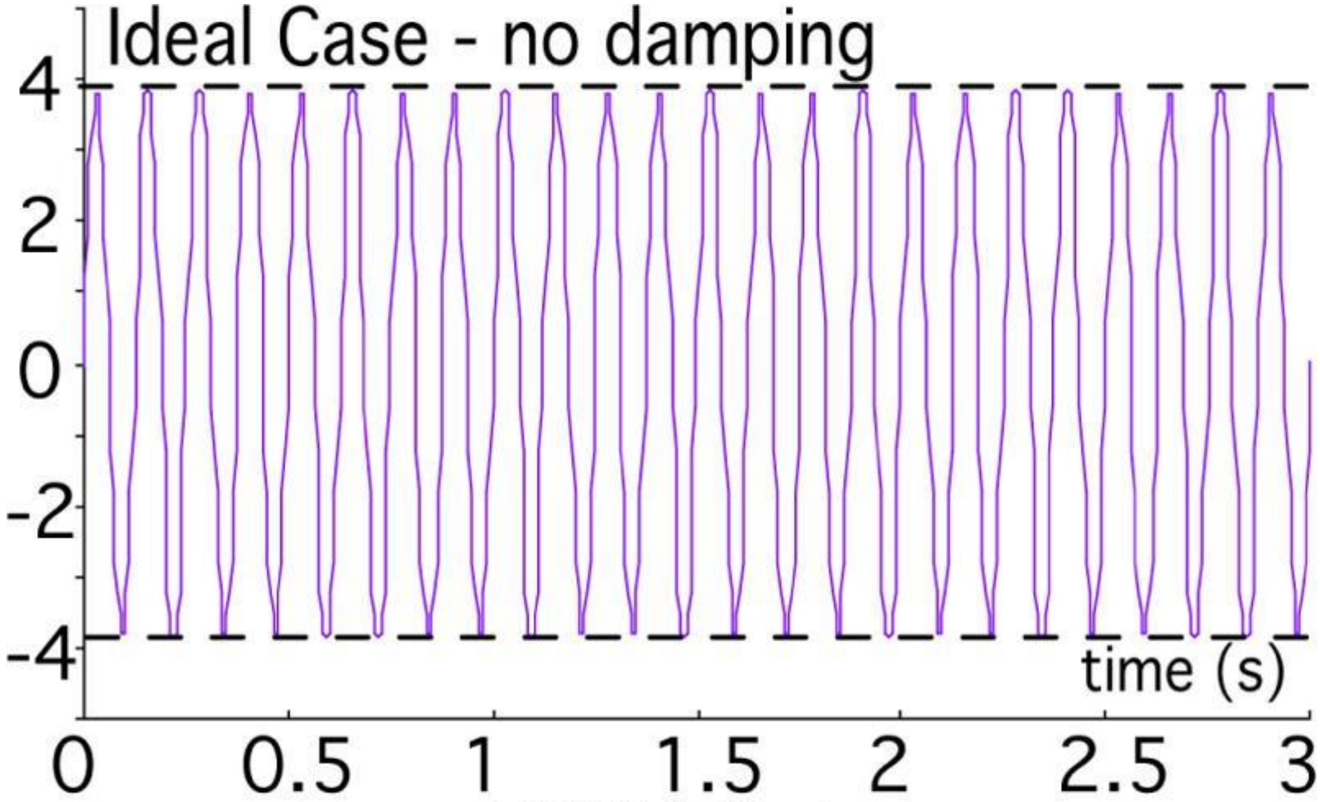
- Understand what “damping” is and why it occurs
- Calculate damping time
- Define “resonance” and “resonance frequency”
- Create superpositions of sound

We know sound is a wave…

Why can’t the other side of the room hear me if I speak quietly?



Ideal cases: most assumptions

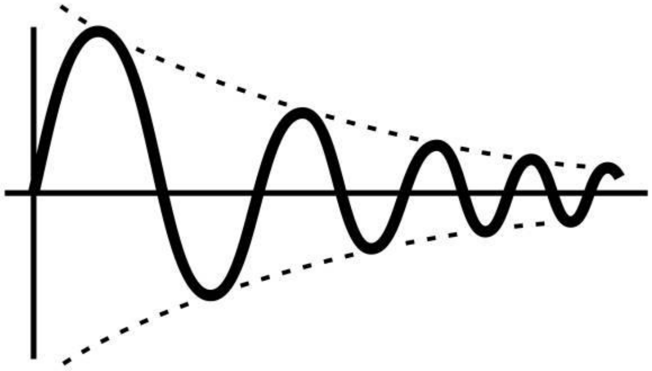


Why does this person stop sliding?

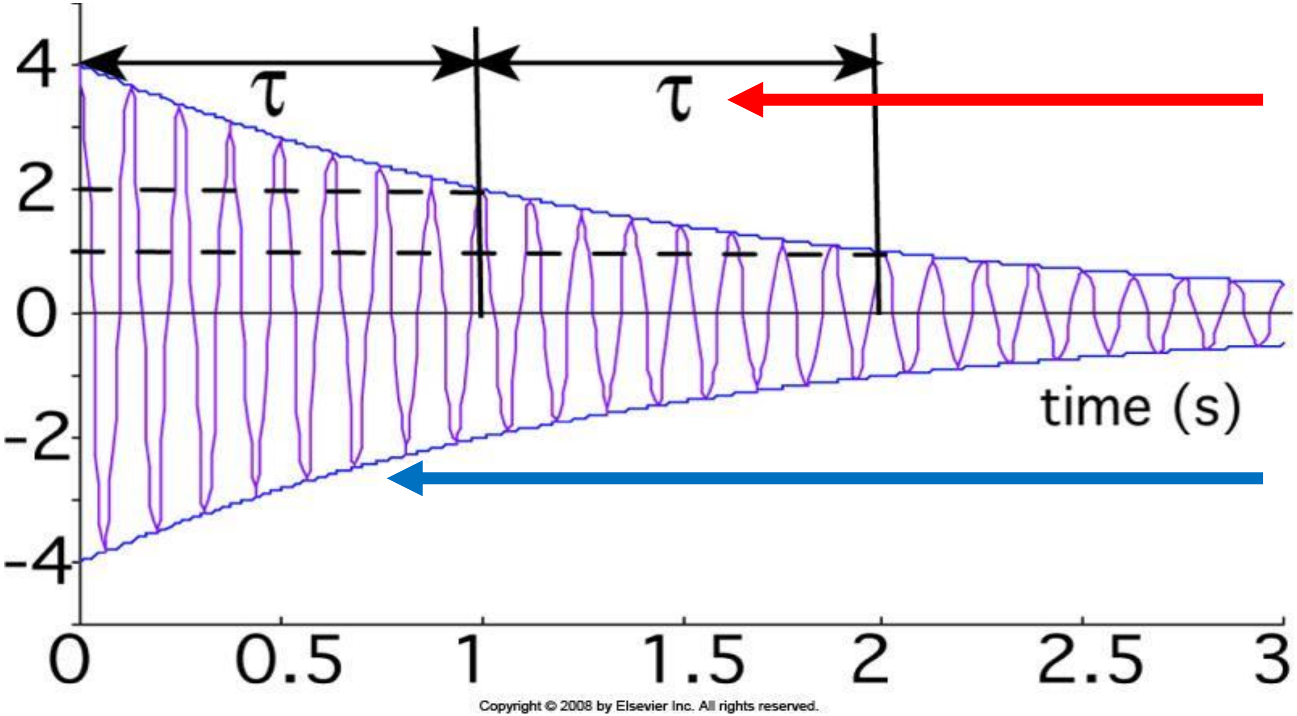
Friction!

Friction: resistance to movement

- Air experiences a type of friction too – air resistance
- Damped sine wave: a smooth, periodic **oscillation** with an **amplitude** that approaches zero as time goes to infinity
- Quick check: if there is more air resistance, will the amplitude more rapidly increase or decrease?
    - Decrease! It will be quieter



How do we quantify how fast this decrease happens?



τ: "tau", damping time
Time taken for the amplitude of an oscillator to decrease to half

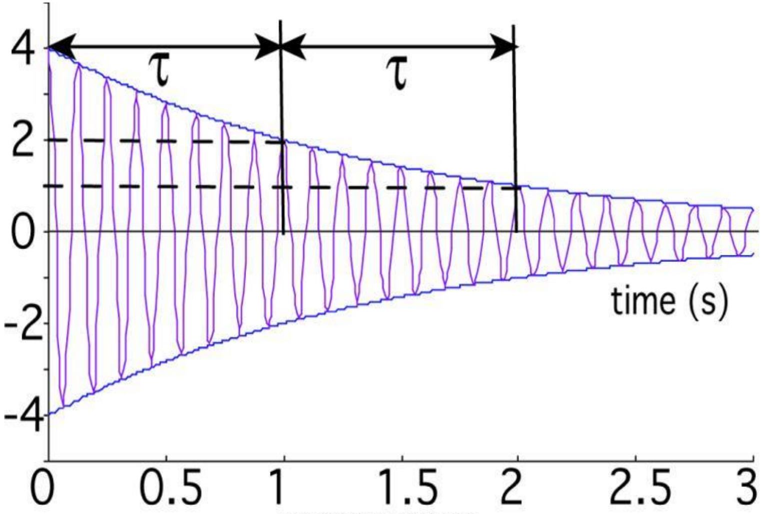
Exponential Decay
½ * ½ = ¼
¼ * ½ = ⅛
….. → 0

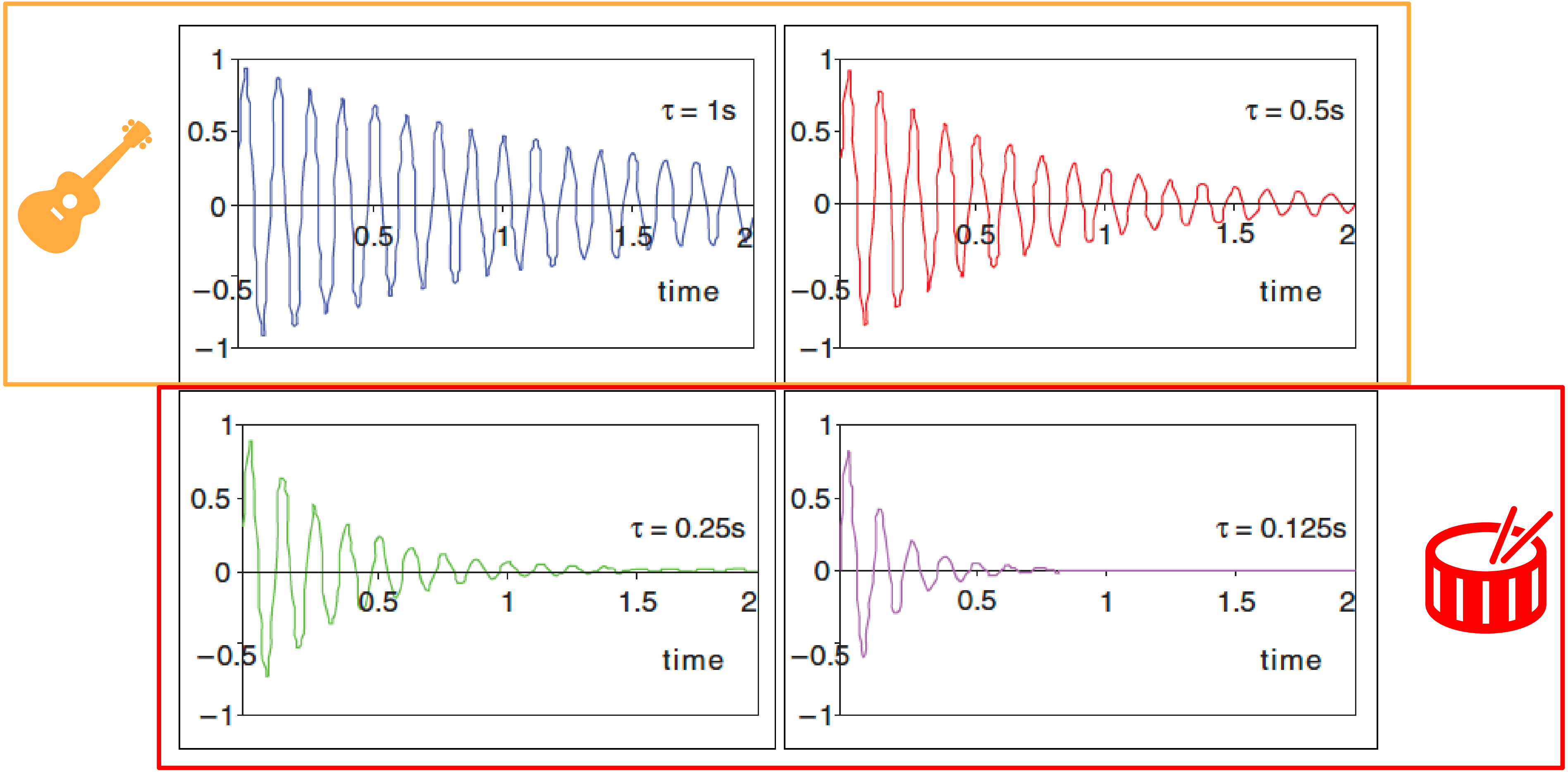
Damping Time calculation depends on your starting point.

What influences τ? What does it indicate?

- Caused by friction/air resistance
- Answer in groups:
  - Choose the right answer for each cell
  - 5 minutes
  - I'll call on groups randomly

	Long τ	Short τ
Friction?	Little/A Lot	Little/A Lot
Damping?	Light/Heavy	Light/Heavy
Length of sound?	Short/Long	Short/Long





All oscillations have the same frequency of 8Hz. Damping time varies from 1s to 0.125s

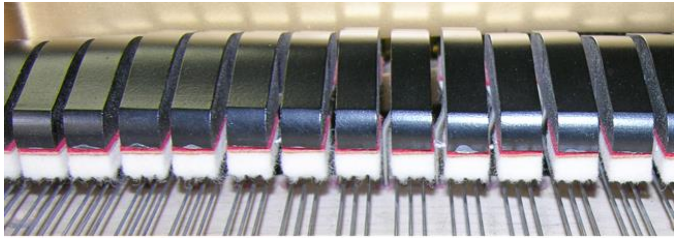
Exercise: Compare Damping Time

- You’re a piano tuner and you’re testing the piano’s damper pedal
- Damper pedals help to *sustain* notes by lifting the damper
- You want a damping time of <u>more than 20 seconds</u>

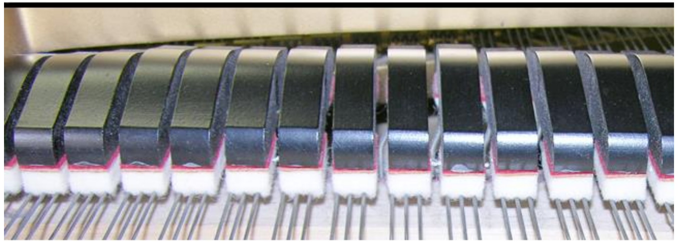
1. Which piano has working damper pedals?
2. Why does releasing dampers lead to sustained notes? Use a key word!

   Friction!

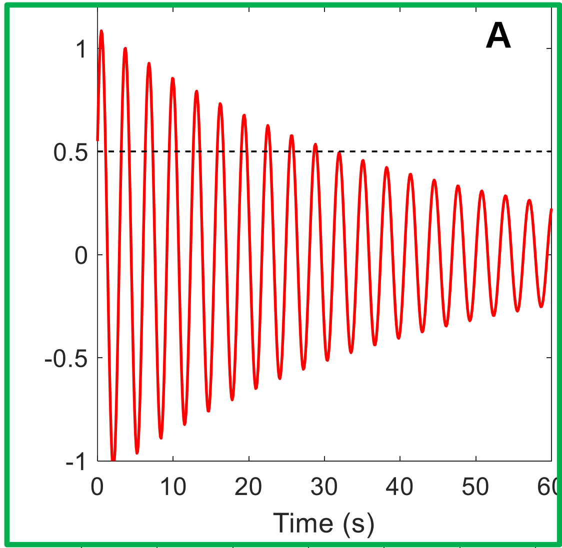
- 5 minutes, we’ll walk around

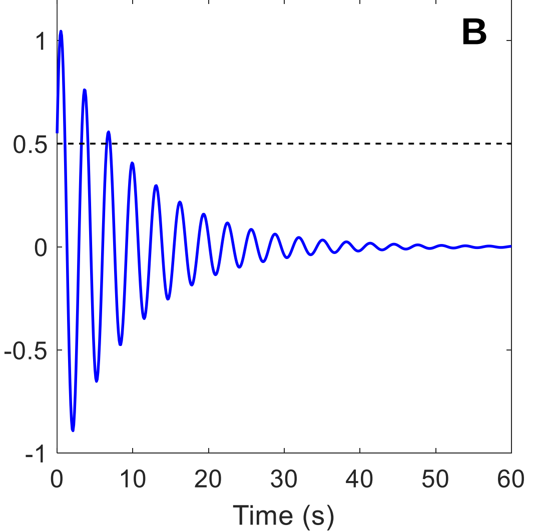


Damper pedal depressed
felt dampers are raised



Damper pedal released
felt dampers are resting on strings





Why can you break a glass with sound?

- Movies and TV shows portray opera singers that shatter car windows with their voice

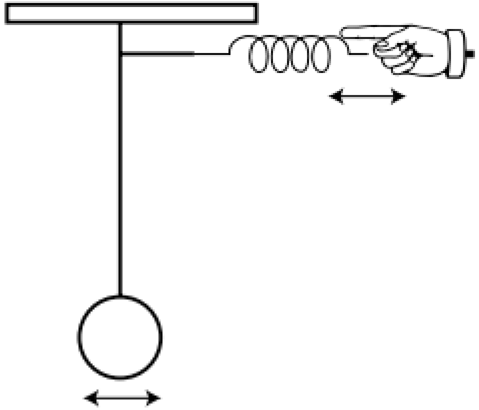
- How is this possible?

- Is this realistic?

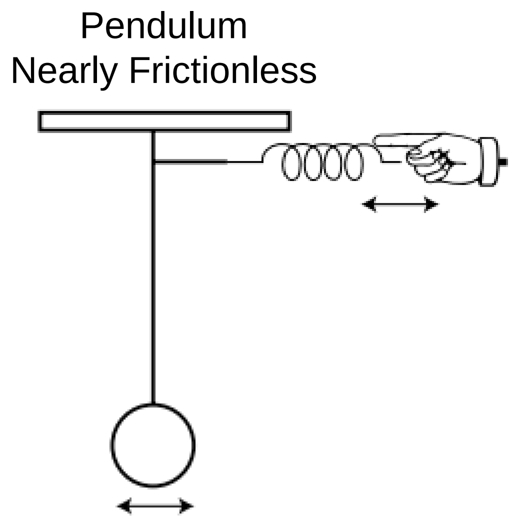
https://decibelpro.app/blog/what-frequency-breaks-glass/

Consider a simpler model first:

Pendulum
Nearly Frictionless



Natural and Driving Frequency



4 Measurements:

Measurement	Definition	For a Pendulum
Natural Frequency: f_N (Hz)	Freq. of oscillation without external force	
Driving Frequency: f_D (Hz)	Frequency of the applied force	
Amplitude of f_D	Magnitude of applied force	
Amplitude of Oscillator	Response of oscillator to the driving force	

How do we know when to push/pull someone on a swing?

- Low frequency pushing:
  not enough external force
- High frequency pushing:
  unnecessary external force

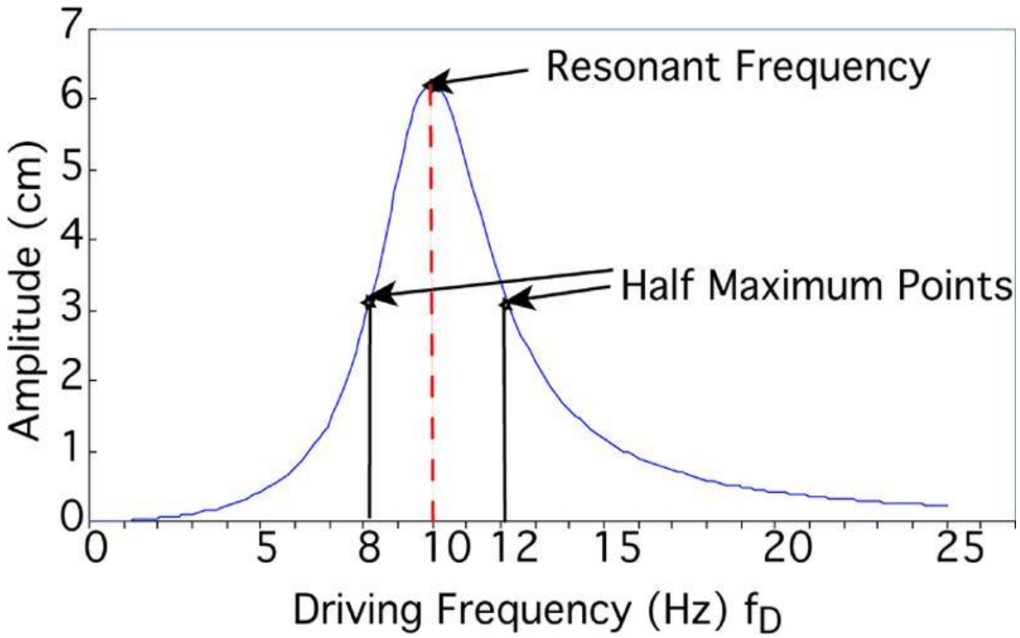
- How do we maximize the height that someone swings?

Resonant Frequency

- To build up the biggest amplitude, the driving frequency f_D should be equal to f_N: this is the **resonant frequency**

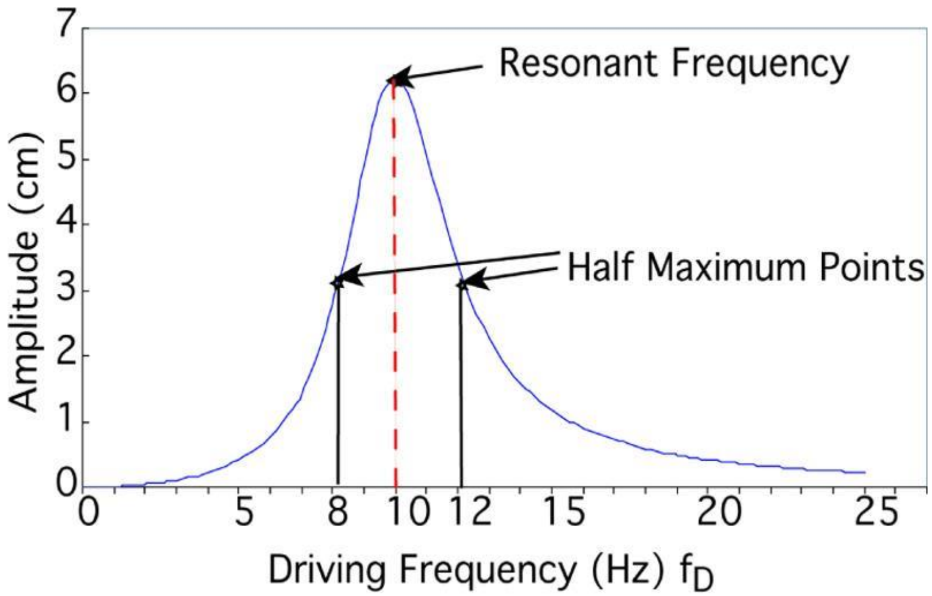
- **Resonance**: response of the oscillating system to outside forces

Resonance Curve

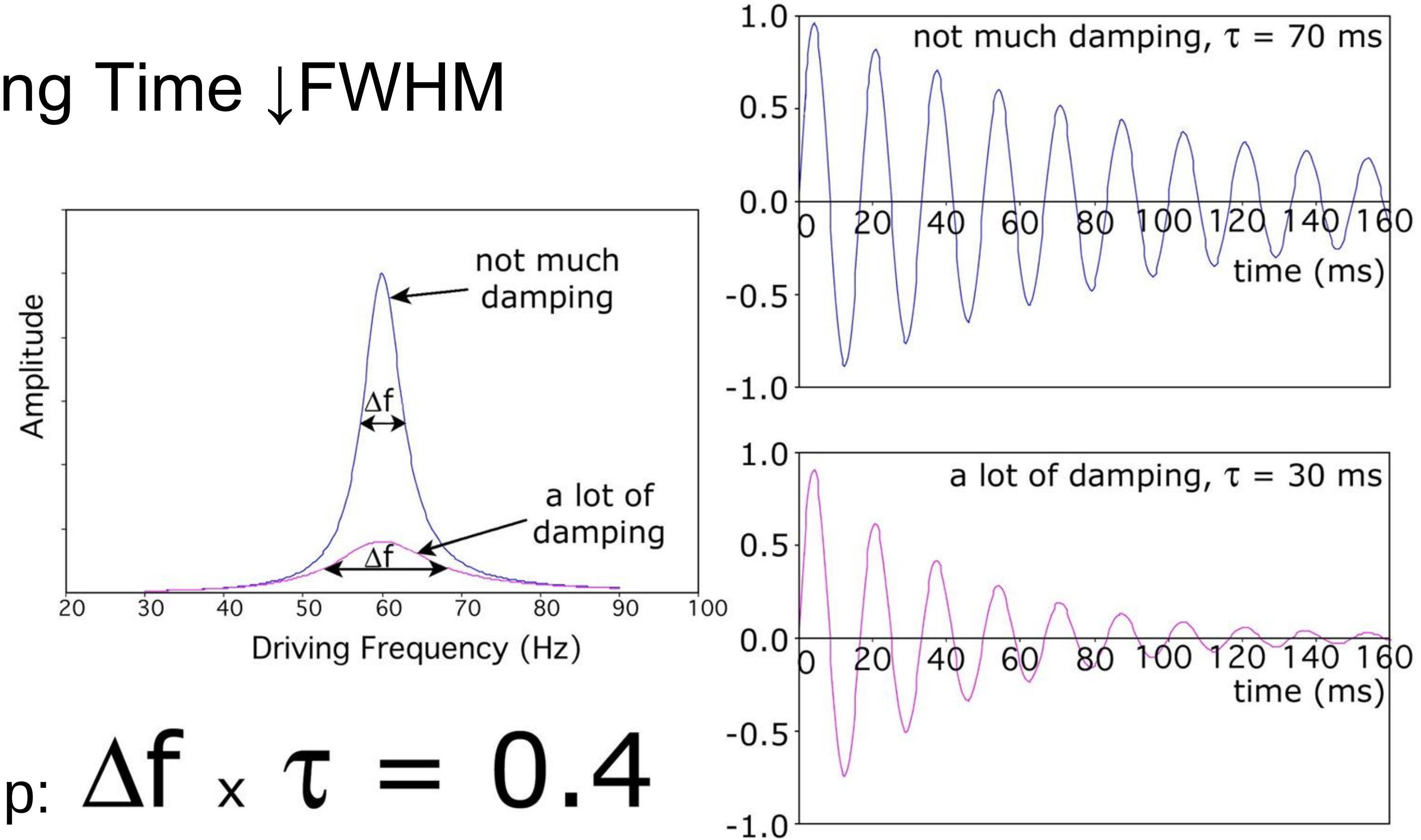


How precise do we need to be?

- Sound can be harder to control
- To get reasonably large amplitudes (50%): look at the **full width at half maximum (FWHM), Δf**
- The FWHM depends on the amount of damping



↑Damping Time ↓FWHM



Inverse Relationship: $\Delta f \times \tau = 0.4$

How do we break glass with sound?

- Lightly strike a glass to get its natural frequency
- Apply a driving frequency to hit the resonant frequency!
- Minimum intensity of 105 dB (normal speech is 60 dB, a lawnmower is 90 dB)

- Short damping time -> lots of friction -> wide resonance curve
- Long damping time -> little friction -> narrow resonance curve

Accomplished objectives

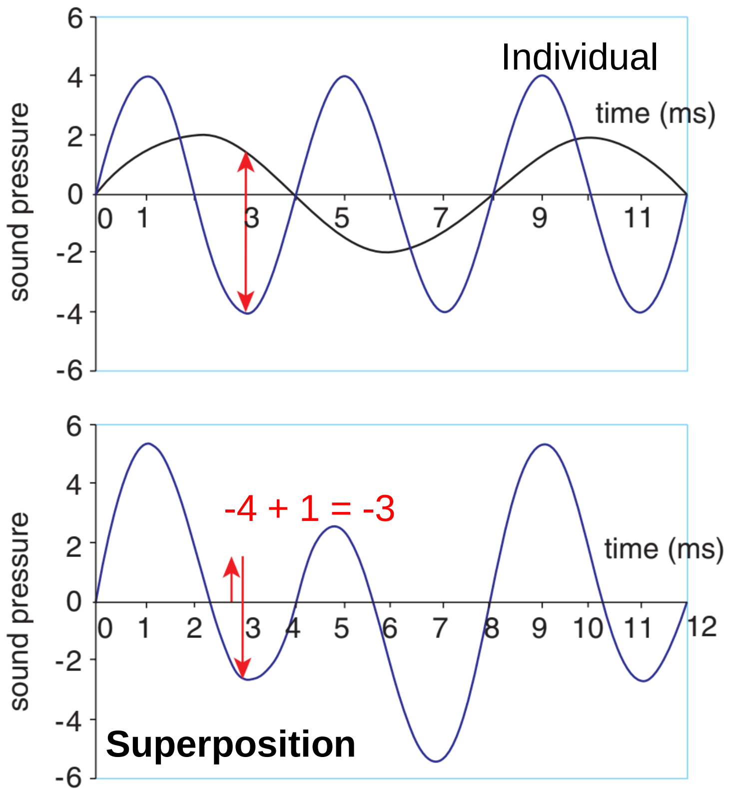
By the end of this class, you will be able to….

- Understand what “damping” is and why it occurs
  - Reduction of amplitude due to friction
- Calculate damping time
  - Time for the amplitude to be halved
- Define “resonance” and “resonance frequency”
  - Response to a driving frequency;
    when the driving frequency = natural frequency
- Create superpositions of sound

How do we detect two oscillations at the same time?

- Sound consists of rapid pressure vibrations
- Multiple oscillations cause different pressure variations
- Different frequencies: different pitches
- **Principle of Superposition:**
  Total Pressure = Pressure 1 + Pressure 2 + Pressure 3…

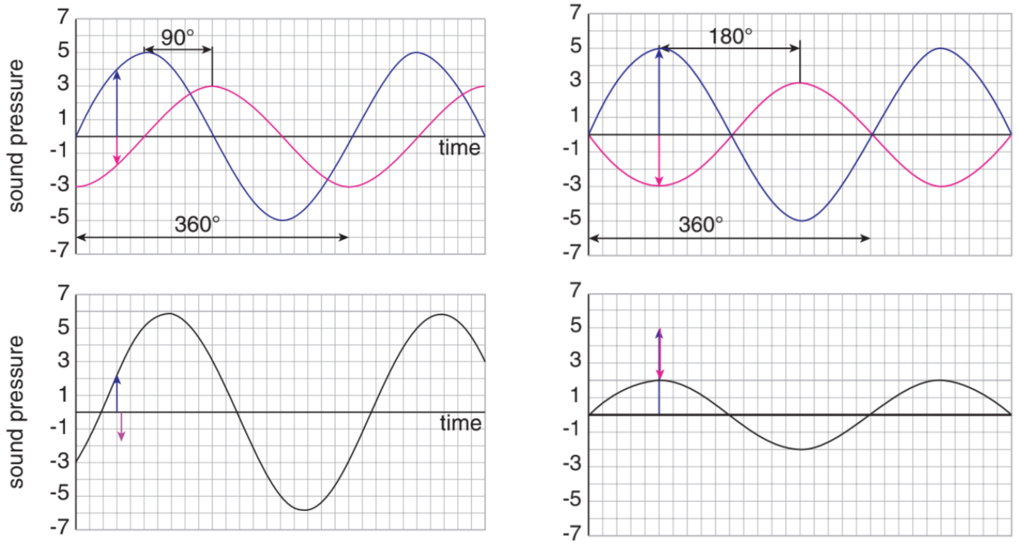
  $P(t) = P_1(t) + P_2(t) + P_3(t) + \ldots$



Two Pure Tones w/Same Frequency

- Pure: i.e. tuning fork oscillations
- Same frequency: same pitch
- Add amplitudes
- Note the **phase shift, ϕ**
  “In-sync” or “out-of-sync”
  - 90° phase shift: ¼ of the oscillation
    (360 * ¼ = 90)
  - 180° phase shift: sounds oppose each other, mainly applies to electronic music production

Individual

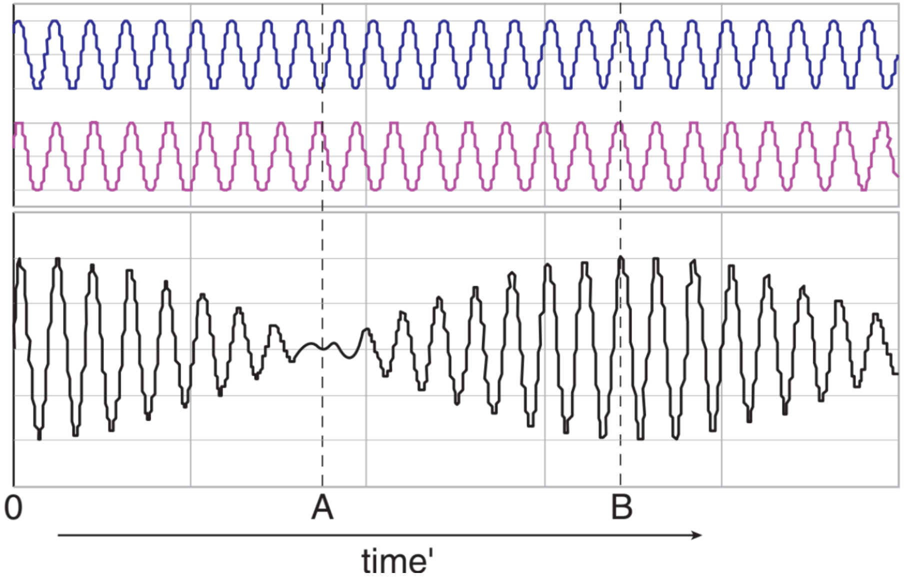


Superposition

Beats: Similar Amplitude, Slightly Different Frequency

- **Beat**: acoustic effect of alternating loud and soft sound due to in-step and out-of-step oscillations
- **Beat Frequency**: Repetition rate of loud and soft alternations, equal to the difference in the frequency of the two sources
  $f_B = f_1 - f_2$

- Quick check: What happens to the superposition amplitude when the sources are “in-step”? What about out-of-step?



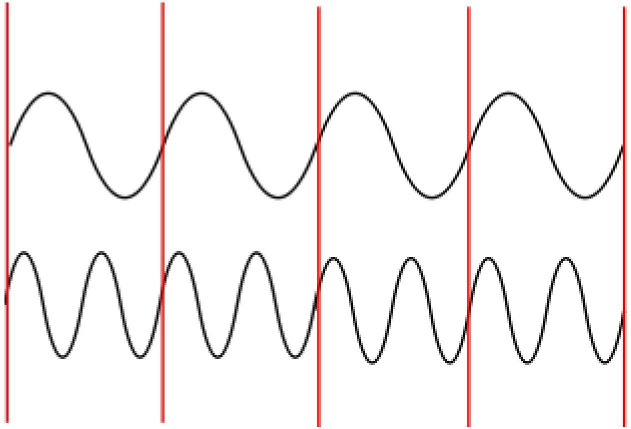
Here's Proof!

Harmony: Frequency Relationships

- **Musical interval**: frequency relationship between two tones
- **Frequency Ratio** determines harmony and dissonance
- Typical rule: simple-number ratios are harmonious

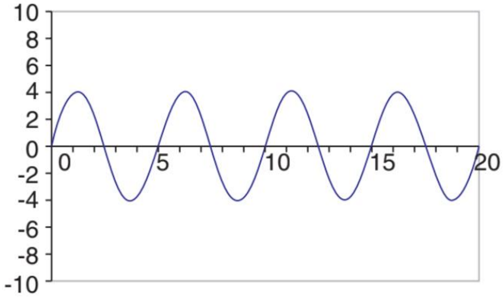
Name of Interval	Frequency Ratio	Example
unison	1:1	300 Hz + 300 Hz
octave	1:2	300 Hz + 600 Hz
fifth	2:3	200 Hz + 300 Hz
fourth	3:4	150 Hz + 200 Hz

Octave

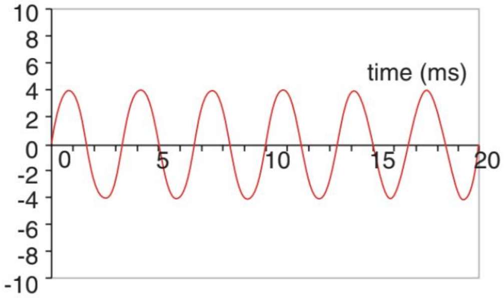


Why are simple-number ratios harmonious?

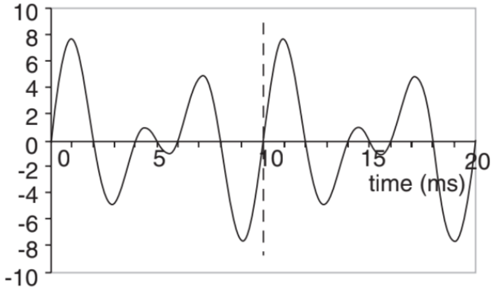
- Because math and physics are cool!
- Eventually, the superposition repeats itself (only harmonious if it’s repeating)
- E.g. for a fifth:



200 Hz Signal



300 Hz Signal. Note that both the 200 and 300 Hz signals are zero at 0 ms, 10 ms, and 20 ms.



The sum (superposition) of the 200 and 300 Hz tones. The period of the sum is 10 ms.

New frequency:
largest common divisor
of the two frequencies

Accomplished objectives

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- Calculate damping time
    - Time for the amplitude to be halved
- Define “resonance” and “resonance frequency”
    - Response to a driving frequency;
      when the driving frequency = natural frequency
- Create superpositions of sound
    - Adding amplitudes and considering phase shifts

Activity!

$$\lambda = f\mathrm{v}$$

$$v = \frac{\lambda}{f}$$

$$f = \frac{\lambda}{v}$$