PHYS1406: Physics of Sound and Music

Spring 2021

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Topics we'll cover this semester

- Preliminaries: Basic math, music, and physics terminology
- Physics of oscillations and waves
- Production of sound (instruments and voice)
- Perception of sound (hearing, loudness, pitch & timbre)
- Auditorium and room acoustics; electrical reproduction of sound
- Musical scales and tuning systems (standardization of musical notes)

Why are you in this class?

What questions about sound & music would you like to know the answer to?

What is sound? What differentiates speech, music, & noise?

- Sound is a **pressure wave** in air (or some other medium, which could be a liquid or solid).
- The pressure wave consists of alternating regions of **compression** and **expansion** of the air molecules.
- **Energy is transferred** from the source of sound to our ears, while the individual air molecules just oscillate back-and-forth in place.
- noise: chaotic, unorganized sound
- speech & music: organized sound
- **musical notes** have a **definite pitch** (low or high), while noise does not

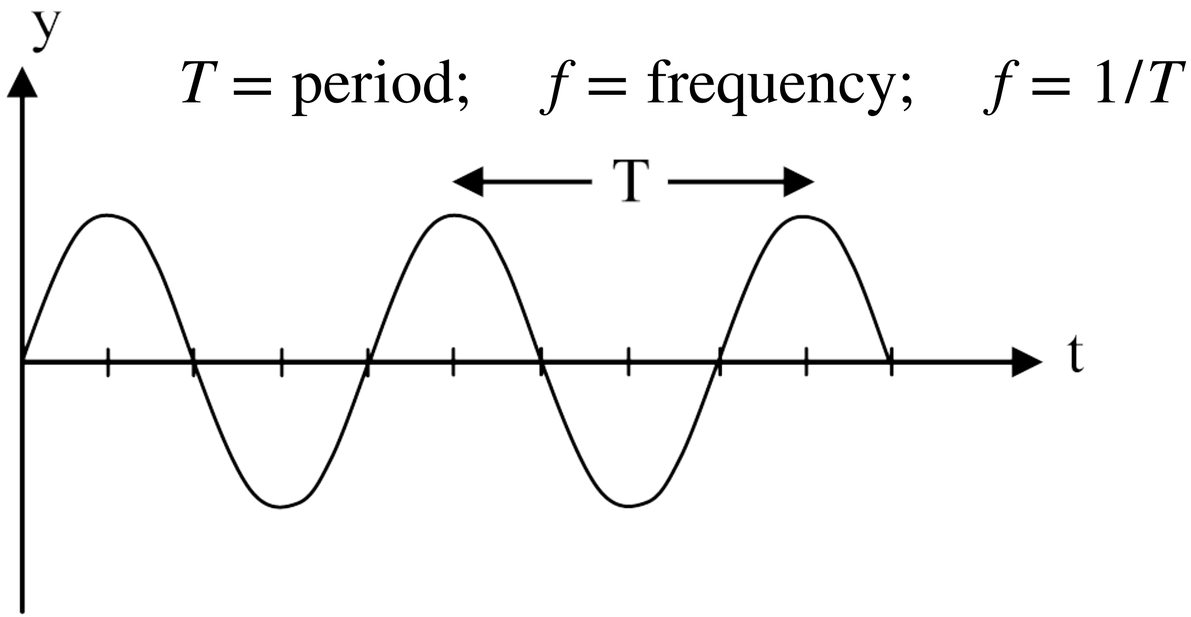
Demos: sound measuring devices & musical instruments

- Measuring devices
  - **oscilloscope**: shows how the sound pressure wave changes in time
  - **FFT analyzer**: shows how much sound energy is associated with different pitch components
  - **spectrogram**: shows how the pitch content of a sound changes in time
- Musical instruments and sound-making devices:
  - whistle, singing, speaking
  - penny whistle, recorder, funny plastic recorder, train whistle, other wind instruments
  - plucked guitar string, bowed violin string
  - bell, drum, shakers, marimba bar, other percussion instruments
  - ratchet, crumpled paper, applause

Range of human hearing

https://www.szynalski.com/tone-generator/

- Normal range: 20 Hz - 20,000 Hz
- What is frequency? Number of repetitions (oscillations, cycles, …) in a given time interval
- Example: Heart rate: 70 beats/1 minute = 1.14 beats/sec
- Hertz (Hz): 1 Hz = 1 cycle/sec



1. Preliminaries

Basic math review

- Entering numbers on a calculator: What's the value of $1/2\pi$? **Ans:** $1 \div (2 \times \pi) = 0.16$ not $1 \div 2 \times \pi = 1.57$
- Fractions: What's the value of 2 divided by 3/2? **Ans:** $2 \div (3/2) = 2 \times (2/3) = 4/3 = 1.33$
- Powers (exponential notation): What's the value of 2^4? 10^3? 10^{-2}?

  Ans: $2^4 = 2 \times 2 \times 2 \times 2 = 16; \quad 10^3 = 100; \quad 10^{-2} = 1/10^2 = 0.01$

- Prefixes:

nano	micro	milli	centi	kilo	mega	giga	tera
10^{-9}	10^{-6}	10^{-3}	10^{-2}	10^{3}	10^{6}	10^{9}	10^{12}

- Comparing two numbers: Compare the heights of two people, one who is 5.5 ft tall versus another who is 72 inches all.

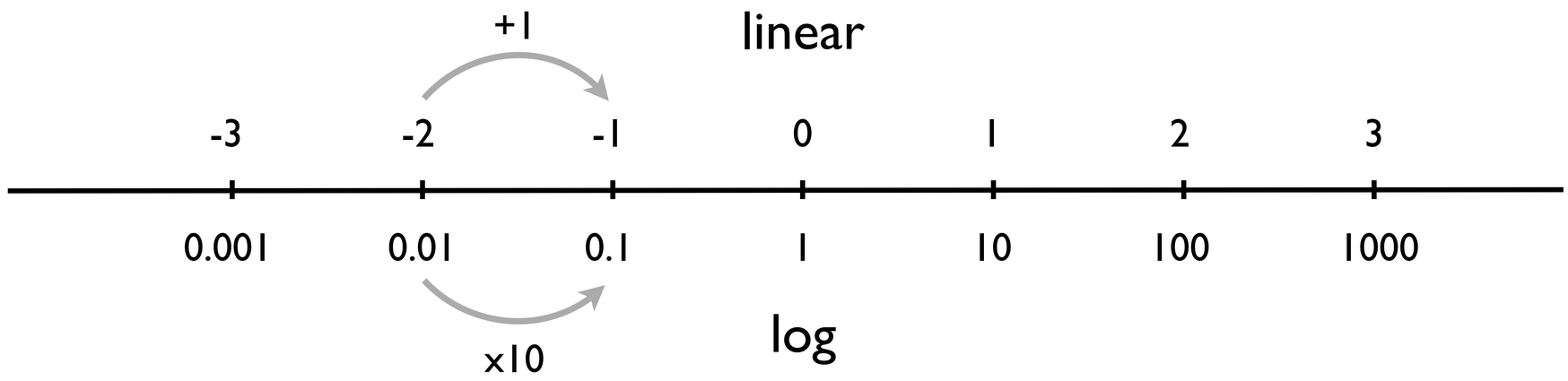
  Ans: First convert 5.5 ft to 66 inches. Then subtract ($72\ \text{in} - 66\ \text{in} = 6\ \text{in}$) or divide ($72\ \text{in}/66\ \text{in} = 1.09$) or calculate percent difference ($100 \times (72 - 66)/66 = 9\,\%$). For music applications, taking ratios or percent differences are most convenient and useful

- Converting units: The speed of sound in air at room temperature (25 celsius) is 346 m/s. What is its value in ft/s? miles/s?

  Ans: Using the conversion factors (1 m = 3.28 ft and 1 mi = 5280 ft), we find:

$$346\ \frac{\text{m}}{\text{s}} \times \frac{3.28\ \text{ft}}{\text{m}} = 1135\ \frac{\text{ft}}{\text{s}} \approx 1000\ \frac{\text{ft}}{\text{s}} \text{ and } 1135\ \frac{\text{ft}}{\text{s}} \times \frac{1\ \text{mi}}{5280\ \text{ft}} = 0.21\ \frac{\text{mi}}{s} \approx \frac{1\ \text{mi}}{5\ \text{s}}$$

Linear vs logarithmic scales

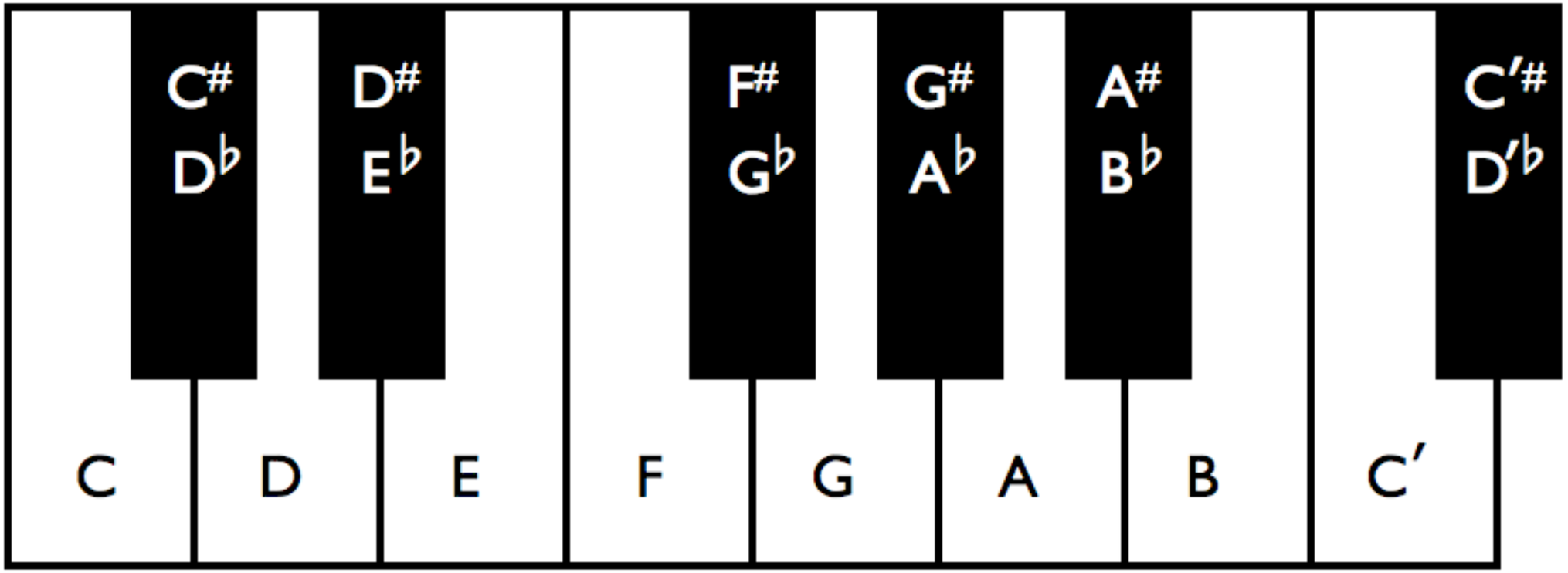


Music terminology

- Pitch: fundamental frequency
- Timbre: richness of a sound, associated with contributions from higher harmonics. It's what makes a guitar sound different from a flute, etc., even though they are all playing the same musical note.
- Octave: Factor of 2 in frequency (e.g., C3 to C4)
- Chromatic, diatonic, and pentatonic scales: divide the octave into 12, 7, and 5 pieces (intervals)
  - https://www.youtube.com/watch?v=jaMA8LWW3C0 (pentatonic scale; all black keys in C-major scale)
- Equal temperament: musical scale where all semitone intervals are equal to one another (6% higher in frequency)
- Musical intervals:
  - **fifth** (C to G; 7 semitones; frequency ratio = 3/2), **fourth** (C to F; 5 semitones; frequency ratio = 4/3), **major third** (C to E; 4 semitones; frequency ratio = 5/4), **minor third** (E to G; 3 semitones; frequency ratio = 6/5)
- Chord: Major chord C-E-G

Chromatic and diatonic scales

C - C# - D- Eb - E - F - F# - G - Ab - A- Bb - B - C′



do – re – mi – fa – sol – la – ti – do