# *Lecture 28 Announcements*

1. Tutorial lab info: I think it will be open during reading days and finals, but the TAs have their own exams to study for and take so staffing may vary significantly from normal.
2. Upcoming:
   a. Colton "class improvement survey" must be done by **tonight** to get extra credit. (I will upload CIDs tomorrow morning.)
   b. TA-led final exam reviews: **tonight** 7-9 pm, 256 CB; **Fri** 3-5 pm, 247 MARB; **Sat** 2:30-4 pm, 247 MARB.
   c. All extra credit and late FBDs must be turned in by midnight Sat, **Dec 12**
   d. BYU Instructor/course ratings must be done by Sat Dec 13. http://studentratings.byu.edu
   e. Final exam in Testing Center anytime during finals week (last day: Fri, **Dec 18**)
      i. 12 problems on Chap 13-14; 4 exam 1-type; 8 exam 2; 9 exam 3; 9 exam 4
      ii. My estimates: 2.5 hrs, 75% average (but I could be wrong!)
   f. All computer-graded homework must be turned in by midnight Fri, **Dec 18** (last day of finals)
   g. I plan to finalize grades on Mon, **Dec 22**, so if there are any problems on your grade report from the class website, you must let me know before then



## Review from last time

1. Doppler effect: $f' = f\,\dfrac{v \pm v_o}{v \pm v_s}$

2. Interference from two paths:
   Constructive if ___________
   Destructive if ____________

3. Standing waves

   Closed-closed & open-open: ___________________

   $f_n = n \times f_1$ ;  n = 1, 2, 3, …

   Closed-open: ___________________

   $f_n = n \times f_1$ ;  n = 1, 3, 5, …

   **Demo**: Flame tube standing waves



## Music (from last time)

**Trumpet** (Let's suppose a "C trumpet" instead of a regular trumpet, so we don't have to worry about the shift between trumpet & piano scales)

The notes you can play with no valves pushed in:

| Note | Frequency | Ratio to Fundamental |
|---|---|---|
| $1^{st}$ harmonic: Low C (with difficulty) | 130.8 Hz (fundamental) | 1:1 |
| $2^{nd}$ harm: Middle C | 261.6 | 2:1 |
| $3^{rd}$ harm: G | 392.4 | 3:1 |
| $4^{th}$ harm: C above middle C | 523.3 | 4:1 |
| $5^{th}$ harm: E | 654.1 | 5:1 |
| $6^{th}$ harm: G | 784.9 | 6:1 |
| $7^{th}$ harm: B-flat?? | 915.7 | 7:1 |
| $8^{th}$ harm: High C | 1046.5 Hz | 8:1 |

**Common chords**: Typically have integer ratio relationships
C-E-G (major) → ratios 4:5:6 (can see from table)
C-E-G-$B_{flat}$ (dominant $7^{th}$) → ratios 4:5:6:7
C-E-G-B (major $7^{th}$) → ratios 8:10:12:15
C-$E_{flat}$-G (minor) → ratios 10:12:15
C-$E_{flat}$-G-$B_{flat}$ (minor 7th) → ratios 10:12:15:18

"One of these things is not like the other"
→ B-flat on piano = **932.3 Hz** **…why?**



## Why isn't the seventh harmonic the same as a B-flat?

**→ "What's a B-flat?"**

**Note:** frequencies increase in **ratios**. That is, freq of $D_{flat}$ = freq of C **times** something, **not** the freq of C **plus** something

**The standard 12-tone musical scale: r = ratio of half-steps**

$$\text{octave}=2f_0 = r^{12} f_0 \quad \rightarrow \quad r = \sqrt[12]{2} = 1.05946\ldots$$

freq of $D_{flat}$ = 1.05946 × freq of C
freq of D = $(1.05946)^2$ × freq of C
freq of $E_{flat}$ = $(1.05946)^3$ × freq of C
freq of E = $(1.05946)^4$ × freq of C = 1.2599 freq of C ≈ 5/4 freq C
freq of F = $(1.05946)^5$ × freq of C = 1.3348 freq of C ≈ 4/3 freq C
freq of $G_{flat}$…
freq of G = $(1.05946)^7$ × freq of C = 1.498 freq of C ≈ 3/2 freq C
freq of $A_{flat}$…
freq of A…
freq of $B_{flat}$ = $(1.05946)^{10}$ × freq of C = 1.782 freq of C
→ high B-flat = 7.13:1 ratio
not 7:1 ratio!
freq of B…
freq of high C = $(1.05946)^{12}$ × freq of C = 2/1 freq C

**Turns out:** All of these notes (except an octave, high C), are a little bit off of the exact ratios. B-flat is just an exaggerated case.

## But why are there 12 tones in a scale, anyway?

→ Because it's the smallest number of tones that can give you close to the right ratios needed for harmonics and chords

- *Fewer* equally-spaced tones in a scale wouldn't get close enough
- *More* equally-spaced tones in a scale would add unnecessary complexity.

## What does this all mean?

| "Equal-tempered" | "Just-tempered" |
|---|---|
| Advocated by Galileo's father, 1581; Extremely influential work by J.S. Bach, 1782: "The Well-Tempered Clavier" | Still used in many instruments, without even thinking about it (just not piano) |
| Same ratio between successive notes: all halfsteps are the same. C to $D_{flat}$ = same as $B_{flat}$ to B | All halfsteps are not equal |
| Makes key changes possible without retuning instrument | Key changes sound very bad unless you re-tune |
| Chords a little off (not exact integer ratios) | Chords are precise (integer ratios exact) |



## Resonance

**From warmup:** If a vibration is made to happen at a natural oscillating frequency of an object, this is called: **(c) resonance**

Swings and springs

Videos: Bowling ball pendulum
Goblet shattering
Tacoma Narrows bridge

Demo: Tuning fork sympathetic vibrations

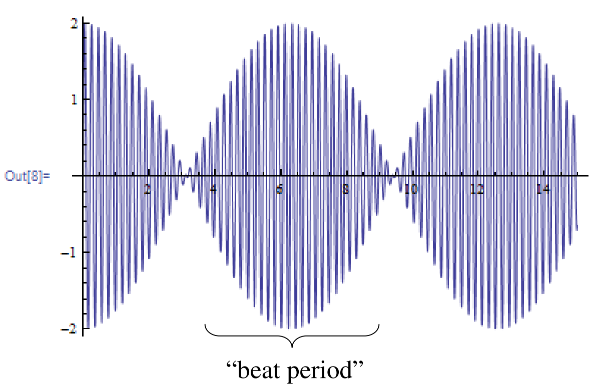
Demo: Trumpet, again



## Beats

Web demo: http://stokes.byu.edu/beats_script_flash.html
Demo: Tuning fork beats

```
In[3]:= f[t_] = Sin[30 t] + Sin[31 t]
Out[3]= Sin[30 t] + Sin[31 t]
In[8]:= Plot[f[t], {t, 0, 15}]
```




"beat frequency": $f_{beat} = |f_1 - f_2|$

**From warmup:** Pianos typically have two or three strings for each note. That is, when you press a single key, a small hammer simultaneous strikes two or three strings. T/F: if the strings are slightly out of tune with respect to each other, unwanted beats can form in the pitch when you play the note. **(a) True**



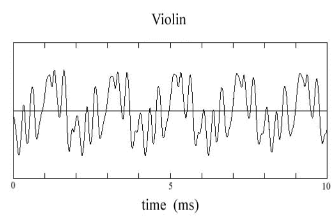
**From warmup:** Help Ralph understand when interference produces standing waves and when it produces beats.

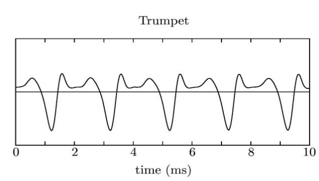
**Answer from the class:**

**From warmup:** A flute and a clarinet both play the same note. Two microphones record the sound wave oscillations. T/F: If the oscillations picked up by the microphones are graphed, the two graphs will look the same.
a. true
b. false

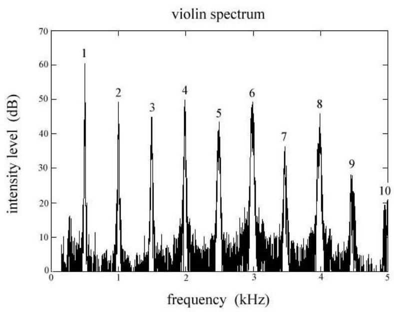
## Tone *quality*: why do various instruments (and voices) sound different for the *same pitch?*

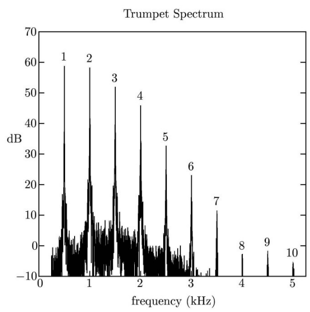
Answer: Real sounds are not usually pure *sine waves*



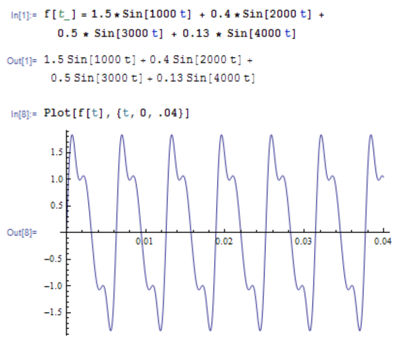
Using a "frequency spectrum analyzer"…




Note: the measured waves are combinations of sine waves.
All of the frequencies present are multiples of the 1st harmonic (the pitch you hear)

Sine waves add together "nicely" when they are multiples (harmonics) of the same frequency. Remember chords!




Sine waves add together "strangely" when their frequencies are not related: typically percussion such as bells, xylophone, tympani, etc.



# Chapters 13&14: Review of important concepts

1. Sinusoidal Oscillations  Asin(ωt) or Acos(ωt)
   a. $A$ is _______________; $\omega$ is ____________________
   b. Period vs. frequency vs. angular frequency
      i. $f = \frac{1}{T}$, $\omega = 2\pi f$, $T = \frac{2\pi}{\omega}$  not given on exam
   c. Simple harmonic motion
      i. spring: $\omega = \sqrt{\frac{k}{m}}$, $T = 2\pi\sqrt{\frac{m}{k}}$  is given on exam
      ii. pendulum: $\omega = \sqrt{\frac{g}{L}}$, $T = 2\pi\sqrt{\frac{L}{g}}$  is given on exam
         1. When does this hold true?

      (just the bare equations are given, not the "spring" or "pendulum" tags)

2. Waves: oscillations that transport energy
   a. Often sinusoidal in space and in time
   b. Longitudinal vs. transverse
   c. Reflections…when does an upward pulse reflect as a downward pulse?
   d. Superposition/interference
   e. Speed, wavelength, frequency: $v = f\lambda$  not given on exam
   f. Wave speed on a string: $v = \sqrt{\frac{T}{\mu}}$, $\mu = m/L$  is given on exam



3. Sound waves
   a. Speed: $v_{air}$ = 343 m/s, unless otherwise specified  is given on exam
   b. Defn of intensity: $I = P/A$  not given on exam
      i. Spherical waves
         1. Surface area of sphere = $4\pi r^2$  is given on exam
   c. Decibel scale (sound): $\beta = 10\log\left(\frac{I}{I_0}\right)$  $I_0 = 10^{-12}$ W/m$^2$  is given on exam
      i. How the log scale works is not given on exam:
         1. +10 to dB number = ×10 to the intensity
         2. +3 to dB number = ×2 to the intensity
      ii. How to solve for $I$?  not given on exam

   d. Doppler effect: $f' = f\frac{v \pm v_O}{v \pm v_S}$  is given on exam
      i. o = "observer", s = "source"  not given on exam
      ii. When to use +/–  not given on exam
         1. If lady (observer) is moving towards baker (source): use + in numerator (because freq increases)
         2. If baker (source) is moving towards lady (observer): use – in denominator (because freq increases)
         3. If moving *away*, use opposite sign.



4. Interference/superposition of waves
   a. Constructive/destructive interference
      i. Waves off by λ vs. waves off by λ/2  not given on exam
   b. Standing waves
      i. Vocabulary: nodes vs. antinodes
      ii. Pictures relate pipe length to wavelength
         1. Closed-closed (string) or open-open (organ pipe, trumpet)

         2. Open-closed (pan pipes)

      iii. What I give you on the exam:
         1. o-o/c-c: $f_n = nf_1$; $n = 1,2,3,...$
         2. o-c: $f_n = nf_1$; $n = 1,3,5,...$
      iv. What I don't give you on the exam: how to figure out the frequency or wavelength of the first harmonic
   c. Beats: $f_{beat} = |f_1 - f_2|$
   d. Only have to know very basic concepts: music/chords

## Physics 105: "What was this class all about?"

1. The universe makes sense!
    a. The order in the universe reflects the order of God
2. The job of a scientist is to discover and make sense of this order
3. The universe can be described mathematically: "Mathematics is the language of physics."
    a. Algebra. Example: Kinematics equations
        i. Position
        ii. Velocity
        iii. Acceleration
    b. Geometry. Example: Area/volume of sphere
    c. Trigonometry. Examples: Vectors, oscillations
    d. Logarithms. Example: decibel scale, work in isothermal process
    e. Calculus. We mostly skipped, but derivatives are crucial to velocity & acceleration; integrals when calculating work
4. Natural phenomena follow natural laws. Examples:
    a. Newton's Laws of Motion
        i. Newton 1: Inertia
        **ii. Newton 2: Forces**
            1. Weight, normal, tension, friction, etc.
        iii. Newton 3: Partner forces
    b. Newton's Law of Gravity
        i. Kepler's Laws
    **c. Conservation of energy**
        i. including work, which can add to/take away from energy of a system



            1. Work is done when a force is applied over a distance
        ii. including rotational energy
        iii. including random energy: "internal energy"
            1. First Law of Thermodynamics
                a. Work is done when pressure is applied with a change in volume
                b. Heat flow is a type of energy transfer
    d. **Conservation of momentum** (if no outside net force)
    e. **Conservation of angular momentum** (if no outside net torque)
5. Sometimes, the behavior of large numbers of objects (e.g. molecules) can be described using overall properties
    a. Ideal gas law
        i. Temperature, pressure, volume
    b. Fluids
        i. Static: Archimedes (buoyancy)
        ii. Dynamic: **Bernoulli** (cons. of energy; pressure vs. speeed)
6. Sometimes, probabilities are all we can talk about
    a. Kinetic theory→ average velocity
    b. Second Law of Thermodynamics
    c. More in quantum physics (some in Physics 106, I think)
7. Matter and energy interact
    a. Radiation
    b. Waves
    c. Much more in electricity/magnetism (Physics 106)



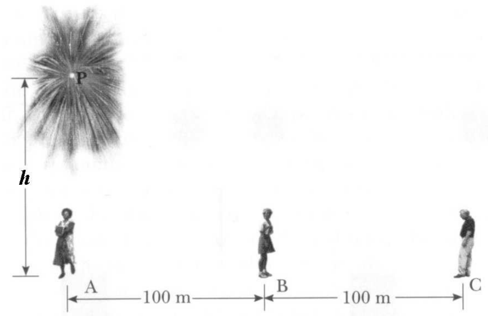
## What I haven't told you about, i.e. "What else is there to learn in physics?"

1. More interaction between matter & energy (much of this in Physics 106)
    a. Electricity & Magnetism
        i. These are "fields"—forces acting at a distance, like gravity
        ii. Currents, circuit elements
        iii. Optics (electromagnetic waves)
    b. Einstein: matter/energy can be transformed into each other, $E = mc^2$
2. Einstein: Newton was wrong! Or at least, incomplete (some of this in Physics 106)
    a. "Special relativity": Newton's Laws of Motion are flawed.
        i. Space & time are relative!
        ii. $KE = \frac{1}{2} mv^2$ flawed: Would take infinite KE to accelerate something to the speed of light.
        iii. …but Newton's Laws work pretty well as long as speeds are not close to speed of light
    b. "General relativity": Newton's Law of Gravity is flawed
        i. …but it works pretty well as long as mass isn't too concentrated (super-high density, like black holes)
3. Quantum physics (some of this in Physics 106)
    a. Not only is a probabilistic description useful, it's *necessary*
        i. Everything is a wave, or at least a "wave function"



    b. Uncertainty: you can't actually know the position and velocity of an object at the same time
        i. …but you can get pretty close if the mass isn't too tiny
4. Particle physics, nuclear physics
    a. Protons/neutrons composed of "quarks"
    b. Many, many other subatomic particles
        i. What kinds?
        ii. Why?
5. Astrophysics/cosmology
    a. What did the universe look like in the past?
    b. What does the universe look like now?
    c. What will the universe look like in the future?
6. Physics of solids (my own research area)
    a. Why are solids different from each other?
    b. How can properties such as thermal expansion, specific heat, electrical resistance, etc., be predicted?
    c. Special kinds of solids
        i. Metals
        ii. Superconductors
        iii. Semiconductors (my own research area)
        iv. Magnets
        v. Many more
7. Much, much more!

**HW 22-4.** A skyrocket explodes at a height h = 123 m above the ground. Three observers are spaced 100 m apart, with observer A directly under the point of the explosion. (a) What is the ratio of sound intensities heard by observers A and B? (b) What is the ratio of intensities heard by observers A and C?




Answers: 1.7; 3.6



**HW 22-5.** A stereo speaker emits sound waves with a power output of 26.6 W. (a) Find the intensity 10.5 m from the source. (Assume that the sound is emitted uniformly in all directions from the speaker.) (b) Find the intensity level, in decibels, at this distance. (c) At what distance would you experience the sound at the threshold of pain, 120 dB?

Answers: 0.0192 $W/m^2$, 102.8 dB, 1.45 m



**HW 23-6.** Two identical mandolin strings under 205.6 N of tension are sounding tones with fundamental frequencies of 523 Hz. The peg of one string slips slightly, and the tension in it drops to 196.7 N. How many beats per second are heard?

Answer: 11.4 beats per second



**HW 23-7.** A speaker at the front of a room and an identical speaker at the rear of the room are being driven at 456 Hz by the same sound source. A student walks at a uniform rate of 1.44 m/s away from one speaker and toward the other. How many beats does the student hear per second? (Take the speed of sound to be 345 m/s.)

Answer: 3.8 beats per second