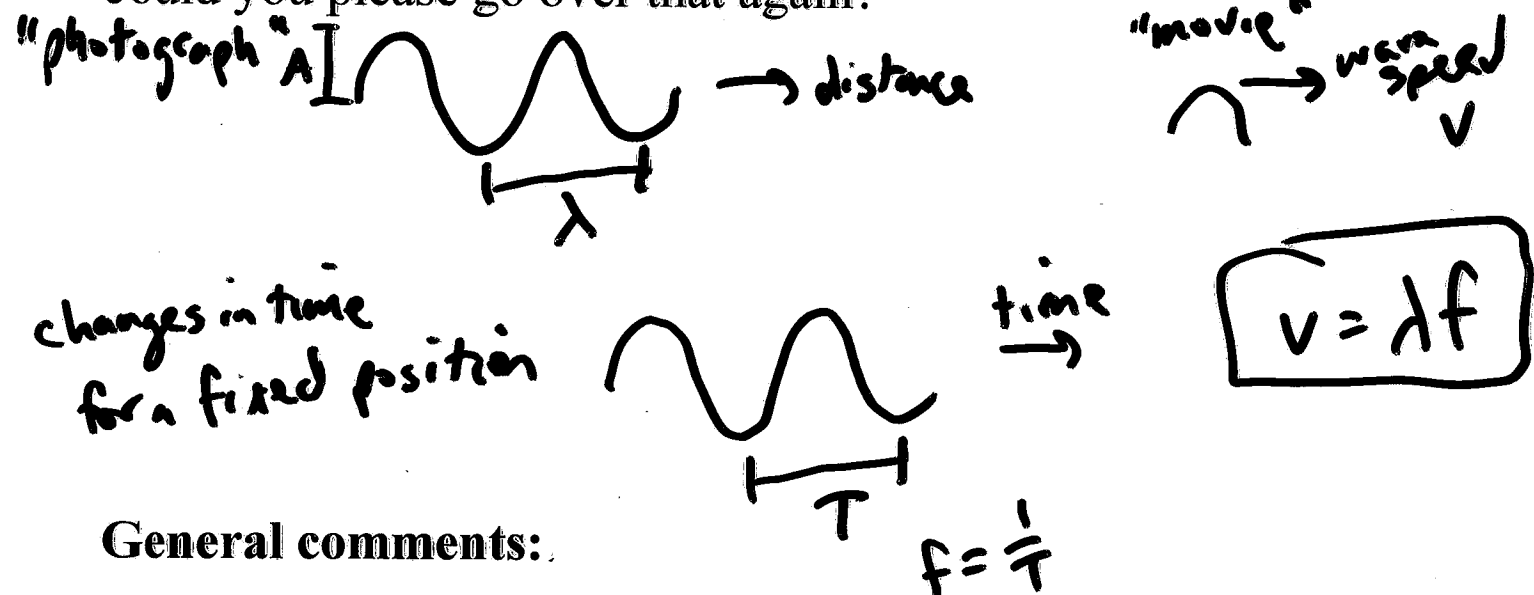# Lecture 28 Announcements

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** Sun
   d. BYU Instructor/course ratings must be done by Sun 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 21**, so if there are any problems on your grade report from the class website, you must let me know before then

Which part of today's assignment was particularly hard or confusing?

I'm having trouble remembering all the terms and what they mean relative to each other (pitch, intensity, frequency and so forth) could you please go over that again?

"photograph" A → distance

λ

"movie" → wave speed v

changes in time for a fixed position

time →

$$v = \lambda f$$

T

$$f = \frac{1}{T}$$

General comments:

How soon will we know what score we received on the Final? *immediately*

The new Star Trek, which I finally just saw, has one scene where some dude floats out into space and there is absolutely no sound. I smiled and told my roommate that it was definitely physics nerds who wrote this movie!

Q: What is the simplest way to observe the optical Doppler effect?
A: Go out at and look at cars. The lights of the ones approaching you are white, while the lights of the ones moving away from you are red. It's so easy! *just joking....*
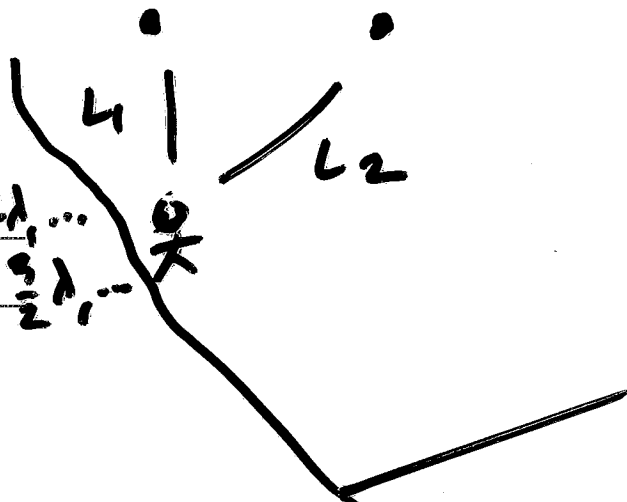
Review from last time

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

2. Interference from two paths:
   Constructive if $|L_1 - L_2| = \lambda, 2\lambda, \ldots$
   Destructive if $\ldots = \frac{1}{2}\lambda, \frac{3}{2}\lambda, \ldots$

3. Standing waves

   Closed-closed & open-open: $L = n \times \frac{\lambda}{2}$

   $$L = \frac{\lambda}{2} = \frac{1}{2}\left(\frac{v}{f_1}\right)$$

   $$f_1 = \frac{v}{2L}$$

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

   Closed-open: $L = n\frac{\lambda}{4}$, $n = 1, 3, 5$

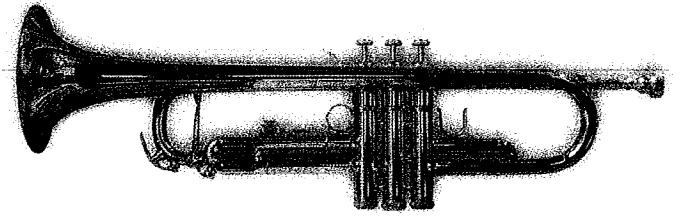 $$L = \frac{\lambda}{4} = \frac{1}{4}\left(\frac{v}{f_1}\right)$$

   $$f_1 = \frac{v}{4L}$$

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

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
1st harmonic: Low C (with difficulty)	130.8 Hz (fundamental)	1:1
2nd harm: Middle C	261.6	2:1
3rd harm: G	392.4	3:1
4th harm: C above middle C	523.3	4:1
5th harm: E	654.1	5:1
6th harm: G	784.9	6:1
7th harm: B-flat??	915.7	7:1
8th 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 7th) → ratios 4:5:6:7
C-E-G-B (major 7th)   → 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 $G_{flat}\ldots$
freq of G = $(1.05946)^7$ × freq of C = 1.498 freq of C ≈ 3/2 freq C
freq of $A_{flat}\ldots$
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
<u>not</u> 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?

"piano ratios

"Equal-tempered"	"Just-tempered" "true ratios
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

force at a frequency
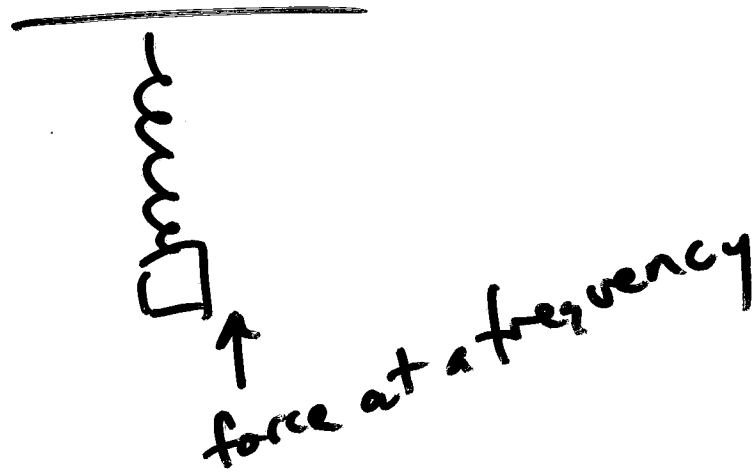
Videos: Bowling ball pendulum
        Goblet shattering
        Tacoma Narrows bridge

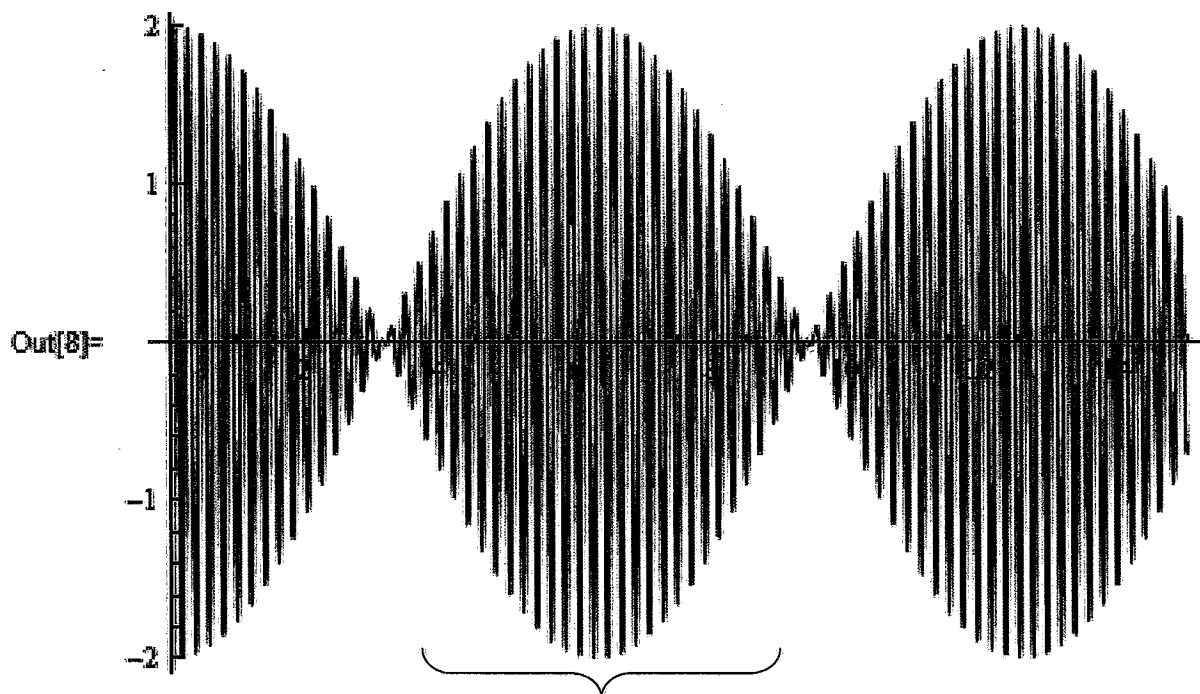Demo: Tuning fork sympathetic vibrations

Demo: Trumpet, again

Beats

Web demo: http://stokes.byu.edu/beats_script_flash.html

Demo: Tuning fork beats $\omega = 30$ $\omega = 31$

```
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}]
```

Out[8]=

"beat period"

"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:

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Ralph, standing waves occur through interference of two waves with the same characteristics traveling in opposite directions in the same medium. Beats, on the other hand, occur through interference of two waves with different frequencies, leading to constructive and destructive interference patterns.

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.
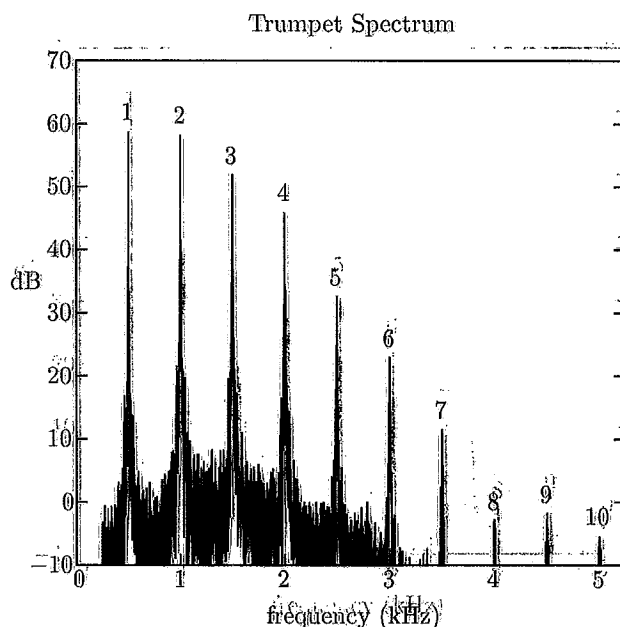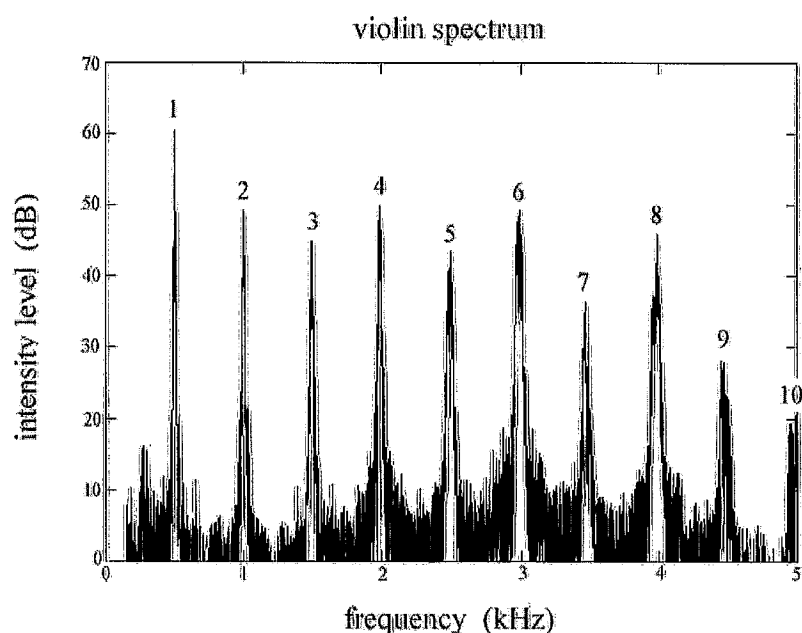
    a. true

    (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*

Violin — time (ms)

Trumpet — time (ms)
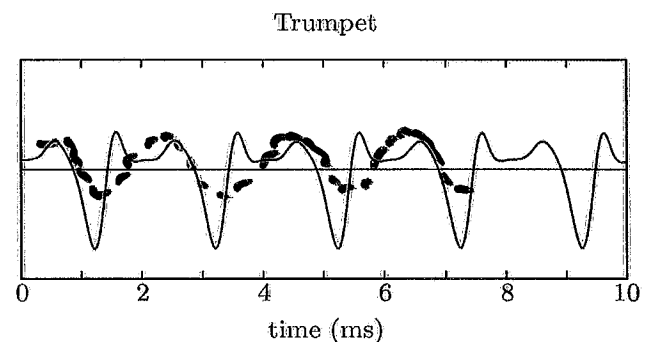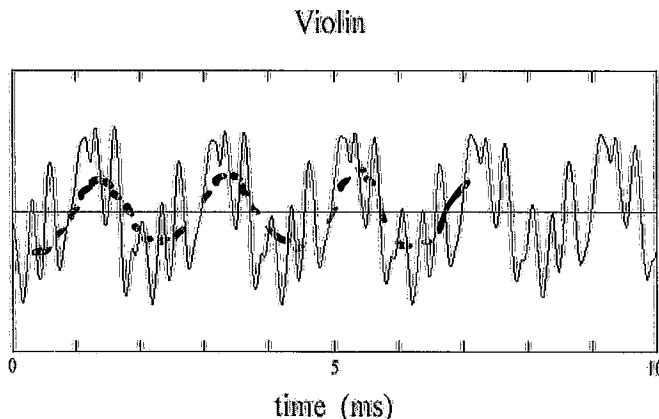
Using a "frequency spectrum analyzer"...

violin spectrum

Trumpet Spectrum

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.

In[1]:= f[t_] = 1.5 * Sin[1000 t] + 0.4 * Sin[2000 t] + 0.5 * Sin[3000 t] + 0.13 * Sin[4000 t]

Out[1]= 1.5 Sin[1000 t] + 0.4 Sin[2000 t] + 0.5 Sin[3000 t] + 0.13 Sin[4000 t]

In[8]:= Plot[f[t], {t, 0, .04}]
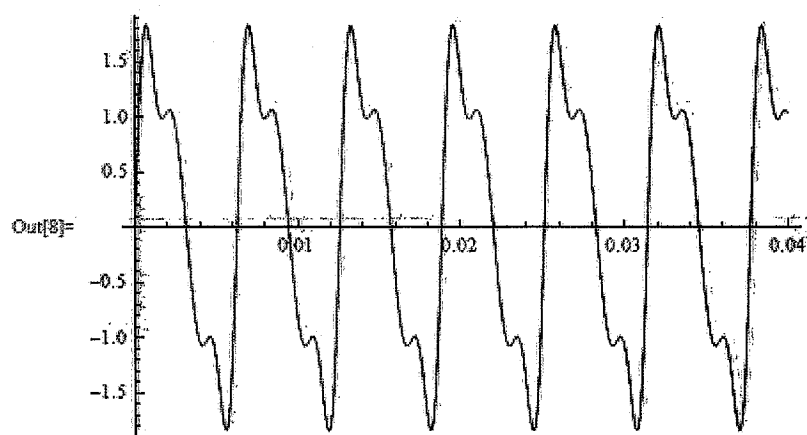
Chapters 13&14: Review of important concepts

1. Sinusoidal Oscillations   Asin(ωt)   or   Acos(ωt)
   a. *A* is **amplitude** ; ω is **angular frequency**
   b. Period vs. frequency vs. angular frequency
      i. $f = \dfrac{1}{T}$, $\omega = 2\pi f$, $T = \dfrac{2\pi}{\omega}$ <u>not</u> given on exam
   c. Simple harmonic motion
      i. spring: $\omega = \sqrt{\dfrac{k}{m}}$, $T = 2\pi\sqrt{\dfrac{m}{k}}$ <u>is</u> given on exam

      ii. pendulum: $\omega = \sqrt{\dfrac{g}{L}}$, $T = 2\pi\sqrt{\dfrac{L}{g}}$ <u>is</u> given on exam
         1. When does this hold true? **small angles**

      (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? **string! if end is fixed**
   d. Superposition/interference
   e. Speed, wavelength, frequency: $v = f\lambda$ <u>not</u> given on exam
   f. Wave speed on a string: $v = \sqrt{\dfrac{T}{\mu}}$, $\mu = m/L$ <u>is</u> given on exam
      mu

3. Sound waves

    a. Speed: $v_{air} = 343$ m/s, unless otherwise specified

                                                               <u>is</u> given on exam

    b. Defn of intensity: $I = P/A$ <u>not</u> given on exam

        i. Spherical waves

             1. Surface area of sphere $= 4\pi r^2$ <u>is</u> given on exam

    c. Decibel scale (sound): $\boxed{\beta = 10\log\left(\dfrac{I}{I_0}\right)}$ $I_0 = 10^{-12}$ W/m^2

                                                                  <u>is</u> given on exam

        i. How the log scale works is <u>not</u> given on exam:

             1. +10 to dB number $= \times 10$ to the intensity

             2. +3 to dB number $= \times 2$ to the intensity

        ii. How to solve for I?   <u>not</u> given on exam

$$I = I_0 \, 10^{(\beta/10)}$$

    d. Doppler effect: $f' = f\dfrac{v \pm v_O}{v \pm v_S}$ <u>is</u> given on exam

        i. o = "observer", s = "source"   <u>not</u> given on exam

        ii. When to use +/–   <u>not</u> 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 *from 2 sources*
        i. Waves off by λ vs. waves off by $\lambda/2$ <u>not</u> 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!