Tu. 1/15: Ch 2 *Waves and Vibrations* **Th. 1/17:** Ch 2 *Waves and Vibrations*	HW2: Ch2: 1[w],13[w], 20[w], Project 1 Ch2: 12, 24	**Mon. 1/14** or **Tues. 1/15:** Lab 2 *Harmonic Motion*

Materials

- Torsion Wave machine (with water can to dampen reflections)
- www.falstad.com/ripple/
- Molecules.exe
  - Wave simulation from last time: http://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html
- Oscilloscope & USB cable (set to display tuning fork / middle C well – let scope turn all the way on before plugging into computer), laptop
- Good (one of older, metal) Microphone
- Tuning fork & resonance box and mallet
- Strobe light (try to pre set it to a frequency around that of the beams oscillations.
- Meter stick / ruler
- Ball
- Clickers and notecards (distributed, one each per seat)

Preparation

Log onto computer and Ppt blackout.

Lab:

Read recommended sections, do pre-lab

Homework Process: How's it going, any questions?

- Look at the syllabus and see the reading and associated problems
- Read and *try* problems
  - If you get the problems right in WebAssign *before* associated class, you get bonus
  - If you don't get problems right, you know what to ask about in class
- If you try a couple times and just don't get a problem *stop* and ask for help – that's what I'm here for.
- Note: while *I* don't need a hard copy of anything you turn in via WebAssign, you should note your work in your notebook so you've got that for reviewing when an exam rolls around.

Clickers

- We're easing toward using these for real (for grade). Please write down a) in the front of your notebook or your textbook (or somewhere else you'll always bring to class) the number of the clicker before you; also please write its number and your name on the note card – that's for me.

This time

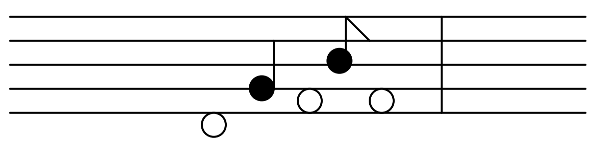
- Chapter 2.
- Last time, we'd gotten just to the threshold of talking about sound *waves* by thinking about how a 'push' of a speaker head propagates through the air. Before going the next step, though, we're going to step back and generalize a little, talk about functional relations. With some of that mathematical / conceptual preparation under our belts, we'll come back to our real subject – sound waves.

2.3 Functional Relations

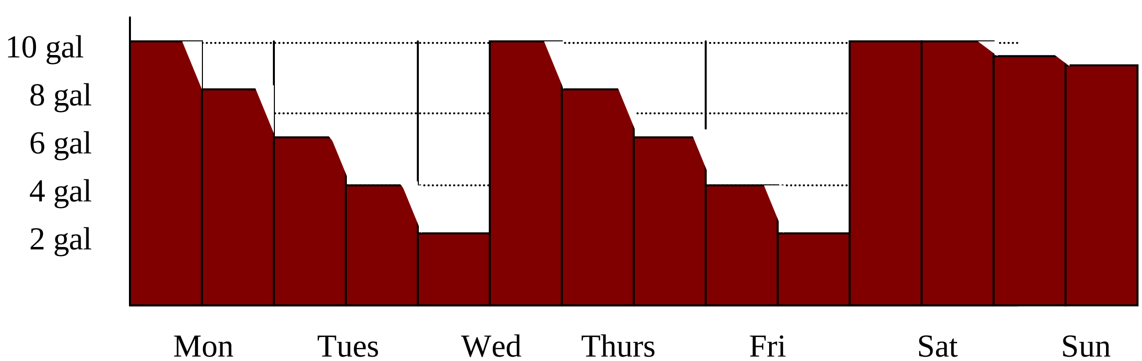
Introduciton: As a single 'push' from a speaker head propagates through the air, we can say, in slightly mathematical ling, that the air pressure varies *as a function* of time and location – how much pressure a microphone detects depends on exactly when and exactly where we look. For discussing how its properties depend on position and time, it is convenient to represent the dependence in a plot. For a moment, we'll diverge from the subject of sound waves and talk about other, perhaps more familiar, things with functional relations.

Examples

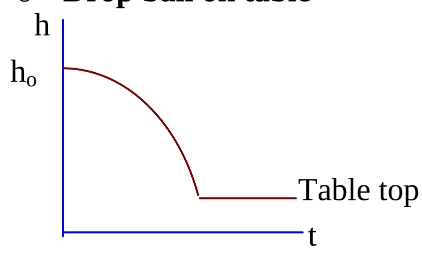
- **Music**
  - In a piece of music, what notes are being played at any instant depends on how far into the piece of music that instant is – the note played then varies as a function of time (if not a mathematically "continuous" one.)
  - **Graphical representation**
    - A sheet of music plots the relationship, note as a function of time: notes up and down the scale, ~ time along the measure.



- **Gas in my car**
  - Back when I was living in Minneapolis and teaching at St. Olaf, about 50 miles out of Minneapolis, the gas in my tank had a pretty regular and dramatic dependence on the day of the week. Gas in my car's tank as a function of time (full around 10 gallons, use 2 gallons each way, refill when it gets to about 2).



- **Height of dropped ball**
  - Once I release the ball, how far it's fallen depends on when I look.
  - ($h - h_o = -\frac{1}{2} g t^2$).
  - **Drop ball on table**



Last Time

Okay, so let's get back to the functional relationship that we're interested in – pressure varying through the air as sound propagates out.

Molecules.exe
Gas Properties

- **Temperature**
- **Pressure P = F/A**
  - **Force**

Sound Propagating through air

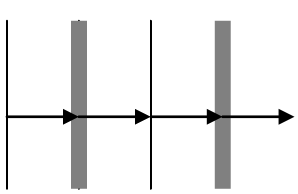
- **Compression:** front where the density and pressure is increased.
- **Rarefaction:** front of lowered density and pressure.
- **The pulses propagate, but the medium does not**
- **Speed of Sound**
  - **Speed**: v, change in position / change in time.

$$v = \frac{x_f - x_i}{t_f - t_i} = \frac{\Delta x}{\Delta t}$$

  - For air near room temperature:
    - $v_s \approx 344\ \text{m/s} + 0.6\ \frac{\text{m}}{\text{s}\,°\text{C}} \times (T - 20°C)$ where T is measured in Centigrade.
    - $v_s \approx 344\ \text{m/s} + \frac{1}{3}\ \frac{\text{m}}{\text{s}\,°\text{F}} \times (T - 68°F)$ where T is measured in Fahrenheit.
    -
- **Vibrations & Waves** – We met the idea of waves, but this time we're going to get much more familiar with them.

http://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html

- **Vibrations & Waves**
  - So far, we've pictured one compression or one rarefaction making its way across a room / dance floor. We, as humans, aren't built to *hear* that. It's the repeated compressing & rarefacting: the speaker head pushes in, pulls back, pushes in, pulls back. Each time the



head pushes in, it launches a compression which speeds away at v_s. Each time it pulls back, it launches a rarefaction which speeds away at v_s. Doing this over and over again launches a series of rarefactions and compressions. This series of disturbances propagating through a relatively stationary medium is called a **wave**. From the perspective of individual air molecules, each one cycles through participating in increases in pressure / density, and decreases. From the perspective of these fronts of pressure / density, they travel through the air.

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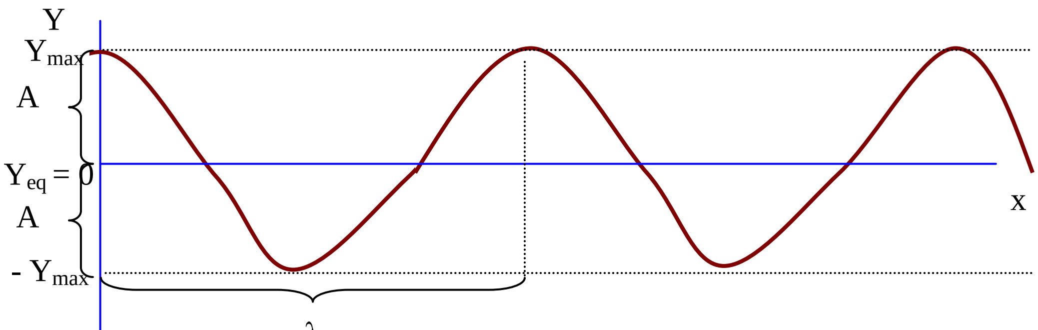
- **2.1 The Time Element in Sound – Period, Frequency, and Wavelength.**
  - **Introduction:**
    - It would be handy if we could *see* our subject matter – sound waves, so we could identify and discuss its properties. This simulation gives us something to picture, but it's a bit messy and just a simulation. Fortunately, we can see many other kinds of waves, and all waves have certain features in common. Thus we can use them to discuss those properties and to visualize sound waves.
  - **Demo: Wave beams**
    - A **wave** could be defined as a *disturbance that repeats through a medium*. In the case of sound wave, the medium is air (in most cases that we'll consider) and the disturbances are the simultaneous changes in air density and air pressure. In the case of the wave beams, the disturbance is the beams' raising and lowering.
    - Dissecting what we're observing, there are maybe four features that we can pick out.

    4 Wave Properties

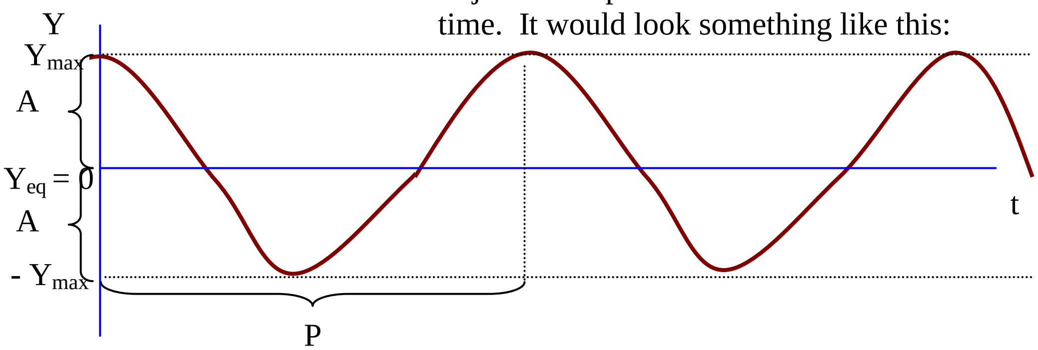
    In lab last week, we'd used some of these, rather on the fly, but now I'll go back and be a little more systematic.



- **Wavelength**, λ. Considering just a snapshot of the wave, the pattern repeats itself through space. The length of one full cycle is called the wavelength.
  - Units: feet, inches; meters, centimeters. A centimeter, cm, is one "cent", or hundredth, of a meter. 1 cm = 0.01 m.

- **<u>Amplitude</u>** – this is a measure of how 'strong' the wave's disturbance is. Since disturbance varies over time and space, a meaningful definition is the maximum disturbance. In the case of the beams going up and down here, that's the *magnitude* of their displacement from equilibrium.

- **<u>Period</u>, P** - focusing on any one of the beams, it is repeating its motion over and over again as time rolls along. We define the period as the length of time over which the motion is exactly repeated, or executes one full cycle.
  - **Plot** – Say we now plotted out not a snap shot of the whole wave at an instant in time, but the elevation of just one representative beam as a function of time. It would look something like this:



- Say it repeats once every ½ a second, then its period is P = 0.5s. That is, if you blinked every ½ second, then you'd keep seeing the same thing.
  - **Demo: pull blinds and Flash strobe light** at waves on torsion beams and try to make it 'blink' in synch with the wave's oscillations.
  - From the little light coming from the doors, you can 'peek' and make out that the beams are moving, but with each bright 'blink' you can see them in the same location over and over.
  - **Units**: seconds, s. But sounds that we hear have periods that are hundredths or thousandths of a second, so it is more common to use the unit of one thousandth of a second: milliseconds,
    - 1 ms = 0.001 s.
- **<u>Frequency</u>, *f*** – this same information is often phrased just a little differently; rather than saying how many seconds one cycle takes, we can say how many cycles fit into a second. In this case, if it takes 0.5 s for one cycle, then 2 cycles can fit in one second, the frequency is *f* = 2 cyc/s.
  - **Units**: cycles/second, cyc/s, or just plain /s. This is also called a Hertz, 1 Hz = 1 cyc/s. Sounds we hear have frequencies from as low as 20 Hz to as high as

20,000 Hz. Another name for 1000 Hz is the kilo-hertz, or kHz: 1,000 Hz = 1 kHz.

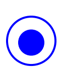
- The mathematical relationship between period and frequency is simply:
  - $f = 1/P$.

Listen with me and watch O'scope

- **Example:** problem 4. 'scientific' Middle C corresponds to a frequency of 256 Hz (**hit tuning fork**); so the air pressure oscillates 256 times per second (because the tuning fork itself wiggles 256 times per second). How much time passes between each wiggle / oscillation?
  - Quantities
    - f = 256 Hz = 256 oscillations / sec.
    - P = ?
  - Relations
    - $f = 1/P$ or $P = 1/f$.
    - P = 1/ 256 osc/sec = 0.0039 sec / oscillation. = 3.9 ms / oscillation.

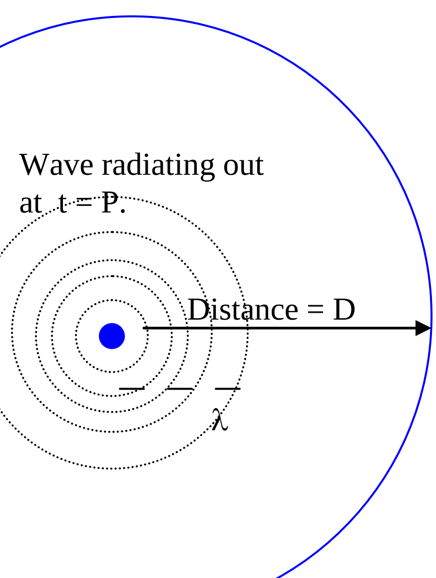
- **Wave-speed,** v_w The definition of the wave speed is the distance a wave peak travels divide by how long it took to do it. $v_w = \frac{\Delta x}{\Delta t}$. Say the wave crest traveled Δx = 2 m in Δt = 1.5 s, then the wave speed would be $v_w = \frac{2m}{1.5s} = 1.33\,^{m}\!/_{s}$.

- **Frequency, wavelength, wave-speed relationship.**
  - The book makes a nice argument for the relationship between frequency, wavelength, and wave-speed. It goes like this:
- **http://www.falstad.com/ripple/**
  -



Wave radiating out at ~ t = 0.

- Starting the clock when one wave crest is produced, 1 second later it will be a distance
  - $D = v_w * 1$ sec out.
  - In the case of sound traveling through the air, that would be $D = v_w * 1$ sec = 344m/s * 1 s = 344 m.
- Meanwhile, wave pulse after wave pulse is emitted, with a frequency of f pulses per second. So the number of pulses produced in one second is
  - N = f*1sec.
  - For a tone at middle A, f = 440 /s, or N = f*1sec = 440 pulses in one second.
- Each wave crest is one wavelength, λ, apart, so the distance from the last one produced to the first one is
  - D = N * λ. = f*1sec* λ.
- But we've also established that
  - $D = v_w * 1$s., so



- v_w * 1s= f*1sec* λ, or
- $v_w = f\lambda$.

- **Demo: $v_w = f\lambda$ on wave apparatus.** If that doesn't quite work for you, perhaps this will. Watch the wave beams, one period, P, is the time it takes for one beam go through one full cycle – starting high, going low and returning high. One wavelength is the length over which the wave pattern repeats itself, for example the distance from the end of the wave in to a beam that is in synch with the end beam. The wave speed is the speed with which the wave crest travels along the medium. So, watch a wave crest start at the end of the beam and travel in. In the time it takes for the end beam to go down and back up (one period, P) you see the crest travel one wavelength, λ, in. So $v_w = \Delta x/\Delta t = \lambda /P = \lambda f$.
- Whatever argument makes the most sense to you, this is a fundamental relationship that holds true for all kinds of waves.
- **Playing Instruments**. We will see that in playing most instruments, the performer manipulates the *length* of a wave, and thereby, through $v_w = f\lambda$,or $f = v/\lambda$, indirectly manipulates the frequency -> the pitch.

clicker question

- **Example** Pr.5 Suppose you measured both frequency and wavelength of a wave, and found them to be 175 Hz and 2 m, respectively.
  - **A)** What *speed of sound* does that imply?
    - A) 0.114 m/s
    - B) 350 m/s
    - C) 87.5 m/s
    - D) I didn't get any of the above
    - **Quantities**
      - f = 175 Hz
      - λ = 2 m.
      - v = ?
    - **Relations**
      - $v = f\lambda$ = 175 Hz * 2 m = 350 m/s.
  - **B)** If the wave is a *sound* wave, in air, then, what *air temperature* does that imply?
    - **Quantities**
      - v = 350 m/s.
      - T = ?
    - **Relations**
      - v = 344m/s + 0.6 m/(s°C) (T – 20°C)
    - **Algebra**
      - T = (v - 344m/s)/(0.6 m/(s°C))+ 20°C = 30°C
      - = 86 °F.

Walk through algebra of rearranging to solve for T.

Water Wave Speed

Demo: Water tank

Hopefully wiggling these beams helps you to get the general idea of waves, but it's probably a little artificial too. Something more familiar and more similar to sound waves is water waves. Water is much like air, but denser, i.e., the mosher's are much more closely packed, so they bump into each other much more frequently for given music (temperature), and they don't wander as far. It also means that while air had some leeway for an increase in density, water doesn't have nearly as much. Pushes near the surface then distort up, creating ripples in the surface. Bouncer's push in, there's nowhere to go but perpendicular.

Peaks and troughs
Wave length

Example: Measure wavelength, read off frequency, what is speed of water waves in this tank?

$v = f\,\lambda$.

Now, it's hard to get the real thing optimized, but you get the idea. Now, let's look at a simulation where it's easier to get things just right.

http://www.falstad.com/ripple/

2.2 Waveforms

Last week in lab you viewed the waveforms of many different sounds on the oscilloscope. The sounds that you made drove the diaphragm of a microphone and its motions were translated into electrical signals which were plotted by the scope. When the sound wave pressed the diaphragm the hardest the signal was largest and when it was weakest, the signal was the smallest.

So far today, we've thought of very simple waves, in which each successive push of air is as strong as the previous, or each successive ripple of the rope is as high as the previous. But this needn't be the case. Indeed, you looked at the waveforms for some fairly complicated sounds in lab.

Change into clicker question

Q: What were some of the sounds that you made into the microphone?
A: A) whistle, B) sing, C) cough, D) tuning fork.
Q: Which sounded "purest" / which sounded the most complicated?
Q: Was there a correlation between this and the appearance on the oscilloscope?

Demo: Different sounds displayed on Oscilloscope

Just as a reminder, the horizontal, or "X" axis of the screen is time and the vertical or "Y" axis of the screen is signal strength.

- **Cough & capture image** – 100 mV, 25 ms
- **Hum** & capture the image (hit run/stop button, use Tecktronix program to display) – 20 mV, 25 ms
  - **Period of complex wave**: when looking at a complex wave, with many peaks and troughs, the frequency of the complex wave = time it takes for the *whole* pattern to repeat. The pattern plotted across the screen mimics

the pattern of the sound waves pushing and retreating from the microphone.

- **Whistle –** 25mV, 10 ms
- **Tuning fork** & capture the image – 10 mV, 10 ms

Conclusion: The purer the tone, the smoother the waveform.

A sound's waveform is the pattern of pressure increases and decreases that produce the unique sound.

Sine vs. Square wave. Intriguingly, one would be hard pressed to argue whether the square wave or the sine wave is the simpler 'shape', but to our ear, the sine wave corresponds to a much 'cleaner' / 'purer' tone. We'll get a piece of the explanation Thursday, but it's not until we study the workings of the ear that we really understand why the sine wave, and not the square, triangle, or some other simple form is what we consider the simplest.