3: Prelab: Metric Unit Prefix

Introduction
In this course it is often necessary to calculate frequencies by taking reciprocals of periods. Sometimes the period will be in units of seconds. With sound signals, however, the period will usually be in the millisecond range, and occasionally even the microsecond range.

Many students have difficulty taking reciprocal of period which is in milliseconds. For example, they will write \( \frac{1}{4.2 \text{ ms}} = 0.24 \text{ Hz} \) or even 0.24 mHz. This is not correct. Remember that 4.2 ms is shorthand for 4.2 \( \times 0.001 \text{ s} = 0.0042 \text{ s} \):

\[
\frac{1}{4.2 \times 0.001 \text{ s}} = \frac{1}{0.0042 \text{ s}} = 238 \text{ Hz}
\]

This homework will give you some practice taking reciprocals of numbers which have prefixes like milli- and micro- on their units. You will need a calculator to do this homework.

Definitions

\[
\begin{align*}
M &= \text{mega} = x 10^6 = x 1,000,000 \\
k &= \text{kilo} = x 10^3 = x 1,000 \\
m &= \text{milli} = x 10^{-3} = x 0.001 \\
\mu \text{ (or } u) &= \text{micro} = x 10^{-6} = x 0.000001
\end{align*}
\]

Procedure

Method 1

The most direct way to calculate a reciprocal it simply to write the number without a prefix before you take its reciprocal. This is what was done in the introduction to take the reciprocal of 4.2 ms. Just write out 4.2 ms as 0.0042 s, put 0.0042 into your calculator and push the 1/x button.

The only problem with this approach is that you may make a mistake when translating the prefix, for example, they writing 4.2 ms = 0.042 s, which is not correct. But if you are careful, you can use this method perfectly well.

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Method 2

Since you will use your calculator to take the reciprocal, it is often more reliable to make use of the scientific notation feature of your calculator to deal with the metric unit prefix. A prefix like m (milli-) means "multiply by $10^{-3}$." That is, $4.2\text{ ms} = 4.2 \times 10^{-3}\text{ s}$.

On most calculators today, you can enter a number directly into the calculator using scientific notation. This is done using a button which is marked either "EE" or "EXP," depending on what brand of calculator you have. To get $4.2 \times 10^{-3}\text{ s}$ into your calculator, you take the following steps:

1. **EE** ← Button for scientific notation (called EXP on some calculators).
2. **+/−** ← Button to get a minus sign (called CHS on some calculators).
3. $42$ $0.3$

At this point, your calculator display should be: $4.2$ $-0.3$. Notice that this means $4.2 \times 10^{-3}$, not $4.2^{-3}$.

Then, to take the reciprocal (to find the frequency) just hit the $1/x$ button. Your calculator display may be $2.381$ $02$, which means $2.381 \times 10^2 = 238.1\text{ Hz}$. (Note: some calculators will display 238.1 directly on their screen after hitting the $1/x$ button.)

The advantage to this method is that you put the number part ($4.2$) directly into the calculator, and then put the unit prefix (milli-) directly into the calculator as $-03$. You never make a mistake counting zeros while moving the decimal point.

Calculations of period from frequencies are done in the same way. Say you have a frequency of $2\text{ kHz}$ and you want to find the period:

$$ T = \frac{1}{f} = \frac{1}{2 \times 10^3\text{ Hz}} = 5 \times 10^{-4}\text{ s} = 0.5\text{ ms} $$

To do this on your calculator, you would push:

1. **EE**
2. $2$
3. $0$ $3$

to get a display of $2$ $-03$. Then your push $1/x$, and the calculator displays $5$ $-04$, which means $5 \times 10^{-4} = 0.0005$. This is the same as $0.5 \times 10^{-3}$, so the period is $0.5\text{ ms}$.

3: Metric Unit Prefix Prelab-2
On the next page you will find some practice problems. Do them and hand them in to your instructor at the beginning of the SoundScope lab period.
If your answer is less than 0.01 or greater than 1000, then express your answer using a prefix. For example, if \( f = 44 \) kHz, then write your answer as:

\[
T = \frac{1}{44 \times 1000 \text{ Hz}} = 0.000023 \text{ s} = 23 \mu\text{s}.
\]

\( f = 16 \) Hz \hspace{1cm} T = \\

\( f = 16 \) kHz \hspace{1cm} T = \\

\( f = 750 \) Hz \hspace{1cm} T = \\

\( T = 0.010341 \mu\text{s} \hspace{1cm} f = \\

\( T = 0.167 \) ms \hspace{1cm} f =

3: Metric Unit Prefix Prelab—4
INTRODUCTION

Your ear is a complicated device that is designed to detect variations in the pressure of the air at your eardrum. The reason this is so useful is that disturbances in the air travel out in all directions as sound pressure waves. If someone slams a door in the next room, the disturbance in pressure travels through the air and soon reaches your ear. Sound waves travel very fast, so even if a car is coming your way at 70 mph, the sound made by the car will probably get to you in time for you to get out of the way.

The first lab introduced you to the way different types of vibrations are perceived as sound. This lab will introduce you to the way sound travels through the air, as a wave. Most of the rest of the semester will be spent examining these two aspects of physical sound in considerably greater detail.

In general, a wave is a disturbance traveling in a medium. If the disturbance is perpendicular to the direction of wave propagation the wave is called transverse; if the disturbance is along the direction of wave propagation – the wave is called longitudinal.

SMALL GROUP ACTIVITIES WITH SLINKIES

Several basic properties of wave behavior can be demonstrated with long springs and slinkies. We will do many of our experiments with springs and strings because you can see the waves on a spring, which you can’t do with sound waves. Your study of sound will be easier for you if you can learn to make analogies to other kinds of waves that you can visualize.

A) Wave Propagation and Reflection

1. Have one person hold one end of the spring and another person hold the other end. Stretch the spring until it is 15 ft long (square tiles in the hallway are 1 ft on 1 ft). One person should send pulses down the spring by jerking the spring to the right and back to center. Do these two motions very fast, to make the pulse as short as possible, but try not to overshoot when you bring your hand back to the center. The pulse should be only on one side:

   ![Wave Diagram]

   Be sure that you understand why this is a wave which you are creating:

   3: Properties of Waves—1
a) What is the medium in this case?

b) What is the disturbance?

c) Is the wave transverse or longitudinal?

All waves have the property that they can be reflected from boundaries. Waves are reflected different ways from different types of boundaries.

d) What happens to the pulses when they are reflected from the fixed end?

B) Speed of a Wave

Many important properties of sound depend on the speed at which it travels through the air, so it is important that you know what speed is and how to calculate it.

Speed is the distance something moves in one unit of time. The easiest way to measure speed is to measure the time it takes it to travel a known distance and then divide the distance by the time. Speed = distance/time.

1. Have a third person use a stopwatch to measure the amount of time it takes for a pulse to go down and back once. It may take several tries to get a good value for the time. Calculate the speed of the wave. Remember, distance = 30 ft (15 down, 15 back.)

   a) How far does this wave travel in one second?

   b) How far would it travel in 15 seconds?

C) Wave Speed Depends on the Medium

1. Stretch the spring out to 20 ft., and once again send pulses down the spring.

   a) From casual observation, does the pulse travel faster or slower than before?

   b) Measure the speed with the watch:

3: Properties of Waves–2
D) Is there Reflection from a Free End?

1. Tie a long string (10 ft. or more) to the end of the spring.

Before you send pulses down the spring, predict what will happen to the pulses when they hit the string. Will they be reflected, or disappear, or do something else? (The spring/string junction is called a “free end” because the string allows the spring back and forth freely. Since this is a transverse wave, only the back-and-forth direction matters as far as the wave is concerned.)

a) Now try it. What happens?

b) Draw sketches showing how this is the same or different from when the wave hit the fixed end.

E) Longitudinal Waves on a Slinky

Coil the long spring neatly in the box and get out the slinky. Most demonstrations work better with the slinky if you only use half of its length, so have the person who holds the fixed end keep half of the slinky all bunched up in his or her hands. Stretch the remaining half of the slinky until it is about 10 ft long.

The slinky is useful because you can use it to make both transverse and longitudinal waves. First, make a couple of transverse waves in the same way you did with the long spring.

1. Now try making longitudinal waves (waves in which the disturbance is in the same direction as the direction of propagation): thrust your hand suddenly toward the person holding the fixed end and then back to its starting point. Do this as quickly as possible, but try not to get any side to side motion. Watch the compression pulse move down the slinky. This is analogous to a region of high pressure moving as a sound pulse in the air; sound waves are longitudinal.

3: Properties of Waves-3
Longitudinal waves are also called "compression-rarefaction waves." Regions where the medium is all bunched together are called regions of compression, whereas places where the medium is a spread out are called regions of rarefaction. In air this corresponds to regions of high and low pressure.

2. If you are careful, you can see a pure rarefaction pulse moving along the slinky. To do this, let out the entire slinky and stretch it to that it covers only 8 ft. Now suddenly jerk your hand away from the person holding the fixed end but do not return it to its original position until the wave has died out.

3. If you push the slinky back and forth you have alternating regions of high and low pressure, like a continuous sound wave in the air. Sketch a longitudinal pulse propagating along the slinky.

3: Properties of Waves-4
INTRODUCTION

The purpose of this lab is to introduce you to more features of the program, PRAAT. We saw in the first lab that we could use PRAAT to record and graph sound signals. In fact, these are the only three qualities that we need to fully describe the steady sounds that are made by objects that vibrate to create oscillating pressure waves.

In the first lab we discovered that we could associate each of the three qualities of sound with a description of what we could hear, see (using PRAAT), or control (using knobs and buttons on the function generator).

<table>
<thead>
<tr>
<th>Quality</th>
<th>Description of sound</th>
<th>Appearance of sound</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>Sounds high or low</td>
<td>Many or few</td>
<td>Frequency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>oscillations</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(horizontally)</td>
<td></td>
</tr>
<tr>
<td>Loudness</td>
<td>Sounds loud or soft</td>
<td>Big or small</td>
<td>Amplitude</td>
</tr>
<tr>
<td></td>
<td></td>
<td>oscillations</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(vertically)</td>
<td></td>
</tr>
<tr>
<td>Timbre</td>
<td>Sounds pure or complex</td>
<td>Shape of sound signal</td>
<td>Function</td>
</tr>
<tr>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

We discovered how to associate changes in the “Controls” with changes in the sound and the appearance of the sound signal. We found that:

- higher frequency sounded higher and produced more oscillations in the same time;
- higher amplitude sounded louder and made the oscillations larger;
- different functions changed the timbre of the sound without changing the pitch (but some people also noticed a change in the loudness).

Today we will use the program PRAAT to measure quantities that are related to Pitch, Loudness, and Timbre. These “quantities” are not new to us; they are the same things that we called “Controls” in the table: Frequency, Amplitude, and Function.

In any science, when we say we will measure something we cannot just go and measure it—we need to define it first. But to define that quantity, all we have to
do is to specify is how to measure it. Some quantities are more useful than others, and have a standard definition. Examples of standard quantities are frequency and period (it is useful to know these definitions for P105 and P106 exams). Other quantities can be made up to suit our purposes.

## Quantifying Sound

Let's define each of the quantities we will use today to describe periodic sound signals (a periodic signal is made up of a small unit called a cycle that repeats over and over again):

- **Frequency**: Count the number of cycles during some time interval and divide by the length of the time interval. [Standard definition]

  This definition is not quite complete, what's a cycle?

- **Cycle**: The smallest repeating unit in a periodic signal. [Standard definition]

- **Period**: Measure the length of time for a known number of cycles, and then divide the time by the number of cycles. [Standard definition]

Is it obvious what the relationship between frequency and period are? Let's call the number of cycles \( N \) and the length of time \( t \):

\[
f = \text{Frequency} = \frac{N}{t},
\]

\[
T = \text{Period} = \frac{t}{N'}
\]

therefore,

\[
f = \frac{1}{T} \quad ; \quad T = \frac{1}{f}
\]

or literally: Frequency = \( \frac{1}{\text{Period}} \) or Period = \( \text{Time for one Cycle} \).

### Amplitude (Peak-to-peak)

Difference (either sound pressure in Pascals or the electrical signal in volts) between the highest point of a cycle and the lowest point of a cycle. (Standard definition for the "peak-to-peak" amplitude of a signal). We will be using this definition in this lab. Note that "amplitude" (with no "peak-to-peak" qualifier) is the usual definition, the coefficient of the sine or cosine function describing the wave, and usually equal to one-half the peak to peak amplitude.

### Function

The shape of one cycle [Standard definition].

3: Using Praat-2
A. Setting up

1. Start up *PRAAT* by double-clicking on the icon marked "Praat" on the computer desktop. While it is starting up, turn on your function generator and make sure it is set to the 1K frequency multiplier (which we now know indicates x1000). Turn the Frequency knob close to 0.2

What approximate frequency is the function generator set to now?

________________ Hz.

Set the Amplitude knob to about half-maximum (near 12 o'clock position). Set the function to the sine wave. Put on the headphones and have a listen.

2. When you started the program, two windows should have appeared: a *Praat* objects window and a *Praat* picture window. Recall how you record a sound with *PRAAT*: choose *Record mono Sound...* from the *New menu* in the *Praat* objects window. A *Sound Recorder* window will appear on your screen.

3. Use the Record and Stop buttons to record a few seconds of your sine wave signal. Type in a name for your sound file (e.g., "sine") in the text box below the *Save to List* button. Hit the *Save to List* button and the text string “sound sine” should appear in the *Praat objects window* that indicates the file where your sound is recorded.

4. With the name of the file highlighted in the *Praat objects window*, hit the *Edit button* to see the waveform that you just recorded in all its glory.

5. To simplify the display (if it is not already done), go across the menu of the *Edit window* (that should be titled "Sound sine")

   - *Spectrogram menu*, pull down, *Show spectrogram* deselect (i.e., if a check mark is shown, select it. If no check mark, exit without doing anything).
   - *Pitch menu*, pull down, deselect *Show pitch*
   - *Intensity menu*, pull down, deselect *Show intensity*
   - *Formants menu*, pull down, deselect *Show formants*
   - *Pulses menu*, pull down, deselect *Show pulses*

3: Using PRAAT-1
B. Function measurement

1. The first thing to do is to identify the shape of cycles (this is how we quantify timbre). To zoom in to show individual cycles, go to the Edit window, View menu, pull down to Zoom... Select a start time of 0.0 seconds and a stop time of 0.1 seconds. 
   Draw the waveform and its shape:

2. Does your picture match the function setting of the generator?

C. Frequency measurement

1. If you followed the directions above, you should be displaying 0.1 second of the signal from the function generator.
   a. Count the number of cycles that the computer recorded. To calculate the frequency, use our definition:

   \[
   \text{Frequency} = \frac{\text{Number of cycles}}{\text{Length of time}} = \frac{\text{0.1 second}}{\text{Hz}}
   \]

   b. Is the answer close to what the frequency generator said?

D. Measuring Period

The most accurate way to measure the frequency is to measure the length of one cycle (the period). We can do this very accurately using "Markers", which give

3. Using PRaat-4
the horizontal and vertical coordinates for the sound signal. There are two markers, indicated by the dashed vertical red lines in the display.

1. Zoom in horizontally so that roughly two cycles are visible in the display as shown below. Do this by using the View menu, Zoom... and entering say 0.0 as a start time and 0.01 as an end time for any relevant combination of Zoom in, Zoom out, Zoom to selection.) Click to place the "start" marker, then drag to place the "stop" marker and let go. The region of signal selected is shown highlighted in pink. You want to measure the time period between adjacent maximum points, or minimum points. Don't worry, you can do it over and over until you get it just right.

![Diagram](image)

2. The time where the start and stop markers have been placed is shown as red numbers at the top of the display. More conveniently, the difference between these two times, and hence the period, is shown in the bar between the two red numbers. The value of 1/T, i.e., the frequency is also shown.

1. Measure the period of your signal using the markers:

   One period = ____________ seconds

2. Since the period is the time for one cycle, the frequency is just:

   Frequency = \( \frac{1 \text{ Cycle}}{\text{Period}} = \frac{1 \text{ Cycle}}{\text{second}} = \) ________ Hz [cycles per second]

3: Using PRAAT-1
E. Amplitude measurement

We can use PRAAT DISPLAY to measure amplitude as well. Leave the display zoomed in on approximately two cycles.

1. You can click anywhere on the waveform and a dashed red vertical marker will appear. The red number at the top indicates the time of the marker location. The blue number to the left of the display gives the amplitude of the waveform at that time as a sound pressure in units of Pascals. Click at several points to try it out.

2. Now try to click at a waveform maximum. You can keep trying, checking that you are getting the largest positive amplitude that you can, e.g., see below where the maximum amplitude is 0.1136 Pascals at a time of 0.005022 seconds.

Record your maximum amplitude: _______________ Pascals.

3. Do the same clicking on an adjacent waveform minimum. It should be a negative number.

Record your minimum amplitude: _______________ Pascals

3: Using PRAAT-6
4. The difference in these two numbers is simply the peak-to-peak amplitude.

Record your peak-to-peak amplitude = Max. amp. – Min. amp.

= ___________ Pascals.

5. Change the function to the triangle wave. Record this new sound waveform. To do so, you have to close the SoundRecord window, go back to the Praat Object window, use the New menu, and choose Record mono Sound… Record for a few seconds, save the file with file name "triangle", and Save to list… With this file name highlighted, hit the Edit button to display the waveform, zoom in on it, and make measurements as before.

6. Draw the shape of one cycle. Measure the period and amplitude. Are period and amplitude independent of the wave shape?
MEASURING MORE COMPLEX SOUNDS

F. Frequency and period of a spoken sound

1. Have your instructor plug in your microphone. Record a vowel sound. Softly singing "eeeee", "aaaaah", or "ooooooo" work best. Remember, you have to close the previous SoundRecord window, and go through the procedure for recording a new wave (see instructions for recording the triangle waveform). See below for an example of the waveform of a sustained vowel "eeeee".

Measure the period, frequency (in Hz), amplitude (in Pascals), and function (show pictorially) of your own sustained vowel.

3: Using Praat-8
2. Put on the headphones again. Set the function generator to a frequency whose pitch you can approximate with your voice. Record a vowel sound at that pitch. Measure the period and frequency. Also use PRAAT to measure the frequency of the signal. Write down measured frequencies in both cases. Are they close?

3. Make a different vowel sound at the same pitch. Measure the period and frequency. Are they close to what you measured in the previous part?
G. Test yourself

A signal has a period of 0.01 seconds, a peak-to-peak amplitude of 5 Volts, and the function is a "ramp" (the drawing below shows one cycle for the ramp function).

Draw the sound signal for a time duration of 0.05 seconds.

What is the frequency of the signal?

3: Using PRAAT-10