INTRODUCTION
The frequency of a sound vibration is associated with its perceived pitch, and since pitch is one of the basic properties of sound, frequency is very important. This hand out will help you to understand the relationship between frequency and period, a related quantity. First, let’s have a quick review of frequency.

FREQUENCY
Frequency tells you how many events happen in a certain unit of time. As an example, try taking your pulse. That is, count the number of times you heart beats in one minute.

Heartbeat rate = ______ per minute

This is a frequency, because it tells how many beats there are in one unit of time. The unit of time you used was the minute, which is customary for pulse measurements. In science, however, the second is the standard unit of time. Since there are 60 seconds in a minute, you will have to divide the number above by 60 to get your pulse in standard units.

Heartbeat rate = ______ per second

Since a typical pulse is between 60 and 85 beats minute, your pulse in beats per second will probably be between 1.0 and 1.5.

PERIOD
Anything that happens over and over again at a regular time interval is said to be periodic. This is because the event is characterized by a certain period of time, namely the period of time it takes for the repeating event to happen once. This characteristic time is called, guess what, the period.

As an example, try tapping your finger of the table once every second (you can come close to one per second by counting “one-thousand one, one-thousand two, one-thousand three...”). You are now making a periodic tapping sound with a period of 1 second—there is one second between taps. Now tap twice as often, every half-second. This makes the period 0.5 s.

Anything that happens repeatedly at regularly spaced intervals is periodic, and the time from the start of one event to the start of the next is the period.
PERIOD AND FREQUENCY

You know that your heart beats in a regular way, so it must be periodic. And since it is periodic, it must have a period. You also know that it has a frequency, because you measured it earlier. Pulse has both a period and a frequency. As another example, you have already seen that each pitch you can hear has a frequency somewhere above 15 Hz and below 20,000 Hz. Since you know that these are steady, periodic vibrations, you know that each pitch must also have a period. In fact, everything that has a period must also have a frequency.

Frequency and period are really just two different ways of saying the same thing. So what exactly is the relationship between frequency and period?

It will be easier for you to remember the relationship between the two quantities if you figure it out for yourself. To see the general relationship, look at a few specific, simple examples. As you write down both the frequency and the period of several periodic events, a rather simple pattern will emerge, which you should summarize in a sentence. (Hint: You will see the pattern more quickly if you express numbers less than one as fractions rather than decimals.)

Remember, frequency tells you how many events happen in a certain unit of time. Period tells you how long it takes for one of those events to happen.

1. Tap your finger once every second, as before.
   a. What is the period? (How long between taps?) ______ sec
   b. What is the frequency? (How many taps in one second?) ______ Hz

2. Tap twice as, often every 1/2 second.
   a. What is the period? _____ sec
   b. What is the frequency? _______ Hz

3. Tap as fast as you can. This will be about 8 times per second.
   a. frequency _______ Hz
   b. period ________ sec

4. Now go the other way; tap slowly, every two seconds.
   a. period ________ sec
   b. frequency ________ Hz

5. Tap very slowly, every 4 seconds.
   a. period ________ sec
   b. frequency ________ Hz

Do you see the pattern? Write a sentence that describes the general relationship between period and frequency.

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2: Frequency and Period Prelab–2
As a general rule, frequencies and periods you measure will not come out to be whole numbers, so you shouldn't leave your answer as a fraction. Instead, you should express your answer in decimal form. For example, you might find that it takes 0.013 seconds for an event to happen once. It doesn't do anyone much good to know that the frequency is $1/0.013$ Hz. It is much more helpful to do the division and write the frequency as 77 Hz.

T AND f

Instead of writing out the words “period” and “frequency” all the time, people like to use single letter abbreviations, so that they can put these variables into mathematical equations. The standard letter for period is $T$ (uppercase) and, in this course, the standard letter for frequency is $f$ (lowercase). If you continue to work and study in a sound related field, you will eventually encounter the symbol $\nu$ (lower case Greek letter $N$, pronounced “nu”) for frequency, but we will use the less technical $f$.

UNITS

Appropriate units have to accompany all measurements (we will take points off when grading if you leave units out). Period is measured in seconds, so always write an "s" after the number, such as $T = 0.013$ s. Frequency has units of Hz, so don't forget to write the "Hz" after the number, such as $f = 77$ Hz.

PRACTICE

Calculate a few periods and frequencies with your calculator.

A. $T = 0.0040$ s  
   $f =$

B. $T = 0.5$ s  
   $f =$

C. $T = 8$ s  
   $f =$

D. $T =$  
   $f = 400$ Hz

E. $T =$  
   $f = 2222$ Hz

F. $T =$  
   $f = 0.75$ Hz

2: Frequency and Period Prelab-3
2: SIMPLE HARMONIC MOTION

Motion of a Mass Hanging from a Spring

If you hang a mass from a spring, stretch it slightly, and let go, the mass will go up and down over and over again. That is, you will get Periodic Motion. Using Logger Pro you can see the repetition in position and velocity graphs. The length of time to go through one cycle of the motion is called the period. If you remember that the period refers to a period of time, you will remember the correct units for the period, namely seconds.

(a) Learning about Logger Pro

In this activity you will examine the graphical display of the motion of a mass hanging from a spring.

1. Open the "Measure Period" file. File – Open – Measure Period. When you double click on the file name the program will open the file.

2. Play with the motion detector to learn about what it does. Aim the detector horizontally off the bench. Click on Collect (or hit the F11 key) and the motion sensor will begin to emit clicks, which means that it is measuring. Start from 4-5 feet (sensor is sensitive up to 2m), move towards the sensor, stop for a second or two when you are 2-3 feet away, then move away from the sensor.

Try to watch the top part of the display as you move or stop: which way does the line move when you are moving toward the sensor? Away from the sensor? Not moving?

3. Now look at the bottom part of the display. It plots your velocity at the same time as it measured your distance. Note that velocity can be positive or negative: which was it as you were moving toward the sensor? away from the detector? at rest?

4. Click Data – Clear All Data

(b) Measuring periodic motion

1. Prepare a mass on a spring. If it hasn’t already been done for you, hang a spring vertically from the support which is mounted to the table and attach the weight holder to the spring. The mass of the holder itself is 20g. In addition, put one slotted mass of 20g on the holder. Place the motion detector face-up directly below the spring.

2. Measure the mass at rest. Try to make the mass stay as still as possible, then click on the Collect button (or use the F11 key). After the program is done measuring, save this data by
clicking Experiment (in the menu bar) – Store latest run – Data – New Data Set. Now click Experiment (in the menu bar) – Data Collection... and set the length for 10 seconds.

3. Make distance and velocity graphs of the motion of the mass. Push the mass straight upward 5 - 10 cm, and let it go. Warning: To avoid making the amplitude too big, push the mass up to start it moving instead of pulling down. Click Collect to begin graphing. The program will measure the motion for 10 seconds.

Before continuing: Be sure the motion detector saw the mass over its full motion and that there are no flat portions of your graph where the mass came too close to the detector.

4. Adjust the distance and velocity scales on the screen so that your graphs fill the axes better, and are easier to read. To do this, click the icon on the menu bar that is an "A" inside a box (to the left of the magnifying glass icon). This is the autoscale button.

5. Print your graph. Select File (in the menu bar), Print Graph, Ok. Click Properties and change the orientation to landscape. Do not change any other printer settings. Click Ok and then Ok again to print your graph.

6. On your print out, label both graphs with all letters:

"B" at the Beginning of one cycle.

"E" at the End of the same complete cycle.

"A" on each spot where the mass is moving Away from the detector fastest.

"T" on each spot where the mass is moving Toward the detector fastest.

"Z" on each spot where the mass has Zero velocity.

"F" on each spot where the mass is Farthest from the motion detector.

"C" on each spot where the mass is Closest to the motion detector.

Comment: Note that when an object returns to the same position, it does not necessarily mean that a cycle is ending. It must return to the same position, and the velocity must also return to the same value in both magnitude and direction for this to be the start of a new cycle.

Question: Compare the distance and velocity graphs. Do they appear to have the same period? Do their peaks occur at the same times? If not, how are the peaks related in time? Select "Analyze" (in the menu bar), "Examine" to help you read the graph accurately.

2: Simple Harmonic Motion - 2
(c) Properties of Periodic Motion—Period and Amplitude

1. Measure the period of the motion represented by the graphs above. Click "Analyze" (in the menu bar), "Examine." Then point the cursor at the beginning of the first full cycle (for example, your first peak) on your distance graph. (You may of course start with any part of the cycle, but be consistent once you pick a starting point.) Note the Time reading (the bottom one of two) in the examine box and write down the number in the table below as the Starting Time. Now find the end of the last full cycle (continuing the example, your last peak), point the cursor at that point and record that as the Ending Time. To calculate the period of the motion, you need to know how many full cycles there are between the two times you just marked. Enter your data and calculation in the first five cells of the top row of the table below. Leave the other cells blank for now.

<table>
<thead>
<tr>
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<td>Large</td>
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<tr>
<td>Small</td>
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</tbody>
</table>

The midpoint of the motion is also the point where the mass will hang at rest. This position is called the **equilibrium position**.

The **amplitude** of the motion is the maximum displacement (change in distance) from the equilibrium position. (For the motion of a mass and spring it should be the same in both directions.) See the diagram below.

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2: Simple Harmonic Motion - 3
2. Find the equilibrium position and the amplitude.

a. Now point your cursor to find the position of the mass when it is at rest. Write down that position in the table above. (This position will be the top one listed in the box.)

b. Also read the maximum distance of the mass when it was oscillating and record it in the table. Finally calculate the amplitude by taking the difference between the maximum and equilibrium positions, and record it in the table.

The motion of a mass hanging from a spring that you looked at in the previous investigation is a close approximation to a kind of periodic motion called simple harmonic motion, often abbreviated SHM.

It is relatively easy to show mathematically that if the restoring force (whatever produces the motion) is proportional to the distance away from the equilibrium position, the result is SHM.

(d) The Dependence of the Period on the Amplitude

1. Repeat the previous investigation with a smaller amplitude. Using the same SHM setup as in the previous investigation (i.e., one spring with the weight holder only plus the 20g mass), make distance and velocity graphs with a smaller amplitude than before. Make the amplitude about half as large as before by only lifting the hanger and masses about half as high as you did the first time.

When you have a good graph, find the period and the amplitude, and record all your data in the second row of the Period and Amplitude data table on the previous page.

2. Compare the periods. Take ratio of the periods and the ratio amplitudes for the two cases.

Ratio of Amplitudes: [Value]
Ratio of Periods: [Value]

Question: Is there evidence that the period depends on amplitude? (Did the change in amplitude result in a comparable change in period?)

2: Simple Harmonic Motion - 4
(c) The Dependence of the Period on the Mass

In this activity you will find out what happens to the period of oscillation when you change the hanging mass. Repeat the period measuring procedure three times, each time adding a 20g slotted mass to the holder. Fill in the appropriate rows of the table.

Then, carefully remove the weight holder and repeat the period measuring procedure with a 10g mass and a 5g mass. These can be attached by slipping the bottom of the spring through a hole in the mass. Fill in the appropriate rows of the table.

(Note: Because the masses are so small, the oscillations will also be very small. It is convenient to double click on the velocity graph and use the Auto Scale feature on the velocity axis. (You can also do this with the distance graph.) When you have just started the oscillation, there will probably be other small vibrations that make the oscillation of the mass hard to see, but these extraneous vibrations will eventually die away enough for you to get good graphs. Keep trying until your graphs are smooth enough for you to measure the period. Then fill in the last two rows of the table.)

Period versus Mass

<table>
<thead>
<tr>
<th>Hanging Mass</th>
<th>Mass [g]</th>
<th>Starting Time [s]</th>
<th>Ending Time [s]</th>
<th>Time Elapsed [s]</th>
<th>Number of Cycles</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holder + 3 masses</td>
<td>80</td>
<td></td>
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<tr>
<td>Holder +2 masses</td>
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<tr>
<td>Holder +1 mass</td>
<td>40</td>
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<td></td>
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<tr>
<td>Holder alone</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>No Holder + 10g mass</td>
<td>10</td>
<td></td>
<td></td>
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<tr>
<td>No Holder + 5p mass</td>
<td>5</td>
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</tbody>
</table>

Question: Does the period depend on the mass. Does it regularly increase or decrease as mass is increased?

2: Simple Harmonic Motion - 5
(f) Graphing the period versus mass

1. Plot the period and mass data. Launch the Graphical Analysis program. Change the labels on the data columns to “mass” and “period.” Enter the data. In the menu bar, click Analyze, Regression.

Comment: It should be clear from your graph that while the period does increase as mass increases, it is not directly proportional to mass, since the intercept is far from the origin. However, your points probably fit fairly well to a line. It could be that the period increases linearly with mass, but offset by a constant. Or it could be that the period depends on mass in some other way, such as being proportional to a power of mass. The only way to find out which of these is correct is to collect more data.
(g) Determining the mathematical relationship between period and mass.

You now have enough data to find the **quantitative** relationship between the period and the hanging mass. The next several steps will allow you to test several hypotheses concerning the period and mass relation. For this purpose you will plot the observed periods versus various powers of mass, e.g. period versus mass to power: 1/5, 1/4, 1/3, 1/2, 1, 2, and try to fit a straight line for each case. From the parameters of the fit (intercept, coefficient of regression (C.O.R.)) you will be able to determine which hypothesis fits the data best. Follow the steps described below.

1. Make a column which is mass raised to a power. Label the data column “mass” by double clicking on the “x” heading. Type “mass” and hit enter. Next, create column to show mass raised to a power by selecting Data (from the menu bar) – New Column – Calculated. For new column name, enter “Mass ^” and then the power to which you want to raise the mass. From the Columns pull down menu, select Mass. Then type “^” and the power you wish to use. Click Ok. Do this for the 1/5, 1/4, 1/3, 1/2, 2 power.

2. Look at your graphs for each of your masses raised to a power. Click on the label on the horizontal axis of the graph to move between your graphs. Then, decide which is the most linear.

3. Find a power of mass which has a COR closest to 1. COR is a measure of how close the data is to a straight line. That is, try to find a power which gives the straightest line which goes through the origin. Use a Regression Line to find the best fit. Write down the values of the slope, intercept and C.O.R. for each tried power of mass. Fill the Table on the next page.

   **Comment:** You will find it impossible to get the line to go exactly through the origin. This is because the spring has some mass, which contributes to the effective size of the hanging mass.

4. When you have the best fit you can get, show it to the instructor, print and attach to your report (one plot per team is sufficient).
Mathematical relationship between period and mass:

<table>
<thead>
<tr>
<th>Power of Mass</th>
<th>Slope</th>
<th>Intercept</th>
<th>C.O.R</th>
<th>Comments/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
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<td>0.25</td>
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<td>0.333</td>
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<td>0.5</td>
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Question: Which of the tried hypotheses fits the data best? In other words, what is the mathematical relationship between the period and mass (to which power of $m$ is period proportional)?

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2: Simple Harmonic Motion - 8