

LABORATORY MANUAL - THE SCIENCE OF SOUND



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Laboratory Manual - The Science of Sound

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CHAPTER OVERVIEW

4.1: Force and Pressure

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4.1.1: Introduction

In this exercise, force and pressure are examined through direct observation in a qualitative manner. Force may be computed by multiplying the mass of an object by acceleration:

$$f = ma$$

If the mass is measured in kilograms and the acceleration in meters per second squared, the resulting unit of force is kilogram meters per second squared, or *newtons* (N). For comparison, one pound of force is equivalent to approximately 4.45 N. A mass sitting on the Earth is affected by Earth's gravitational acceleration, 9.8 m/s^2 , so the force acting on it at rest (i.e., its weight) is the mass in kg times 9.8 m/s^2 .

Pressure is defined as force per unit area:

$$p = f/\text{area}$$

Given a force in Newtons and an area in square meters, the resulting unit (Newtons per square meter) is called a *Pascal* (Pa). Note that pressure can be increased by either increasing the force or by decreasing the area. Even a modest force can produce extremely high pressure if it is applied over an exceedingly small area.

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4.1.2: Equipment

- 1 Meter stick or tape measure
 - 1 Metric mass set
 - 1 Metal plate
 - 1 Sheet of foam rubber
-

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4.1.3: Procedure

Part A: Calculating Force and Pressure

1. Calculate the expected force for the 1000 g (1 kilogram) mass based on the acceleration due to Earth's gravity and record in Table 1.
2. Repeat step one for the 500 g and 200 g masses.
3. Measure the diameter of the 1000 g mass. Calculate the resulting area ($area = \pi r^2$) and record in table two. Using the force computed in Table 1, calculate and enter the resulting pressure in Table 2.
4. Repeat step three for the 500 g and 200 g masses.

Part B: Observing Pressure via Deformation

5. A simple qualitative way of observing pressure is to note the deformation of a semi-soft material. In this exercise, a slab of foam rubber will serve this purpose. Simply place the 1000 g mass on the slab and note the degree of deformation (none, slight, moderate, etc.). Enter your observation in the final column of Table 2
6. Repeat step five for the 500 g and 200 g masses.
7. Using the same force, pressure may be increased or decreased by decreasing or increasing the area, respectively. To increase the effective area, a metal plate may be introduced between the mass and foam rubber. Calculate the area of the plate, and based on this value, calculate the new pressures for the three masses and enter these data in Table 3.
8. Place the metal plate on the foam rubber and position the 1000 g mass in its center. Note the degree of deformation of the foam rubber and record in Table 3.
9. Repeat step five for the 500 g and 200 g masses.
10. To illustrate the effect of decreasing the area, place the plate on the foam rubber on edge, that is, the plate should be perpendicular to the foam rubber. Carefully balance the 1000 g mass on the top edge of the plate (you will have to steady it with your hands) and note the deformation. The area in this instance is the area of the edge of the plate, and thus very, very small compared to the plate face or the bottom of the mass. (This observation is sufficient and there is no need to attempt to measure the area of this edge.)

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4.1.4: Data Tables

Table 1

Mass	Force
1000 g	
500 g	
200 g	

Table 2

Mass	Diameter	Area	Pressure	Observations
1000 g				
500 g				
200 g				

Table 3

Mass	Plate Area	Pressure	Observations
1000 g			
500 g			
200 g			

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4.1.5: Questions

1. What is the affect of increasing mass on force?
 2. What is the affect of increasing area on pressure?
 3. Does the higher of two masses always produce a higher force given the same acceleration?
 4. Does the higher of two masses always produce a higher pressure?
 5. Based on established theory, if this exercise had been repeated on the moon, would you expect the deformations recorded in Tables 2 and 3 to be the same, greater, or smaller? Why?
-

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CHAPTER OVERVIEW

4.2: Speed of Sound

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4.2.1: Introduction

The speed of sound in air at room temperature is approximately 343 meters per second, or 1125 feet per second, and increases with increasing temperature. This velocity is roughly equivalent to approximately 1 foot every 0.9 milliseconds. Thus, for the dimensions of typical class and lab rooms, time delays are generally less than 50 milliseconds, and are therefore difficult to measure without specialized equipment. Digital oscilloscopes can easily resolve time differences several orders of magnitude less than one millisecond, and thus are a good candidate for this exercise. Care must be taken to make sure that no differential delay is caused by the recording circuitry.

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4.2.2: Equipment

- 1 Digital sampling oscilloscope
 - 2 Microphones, stands, and cables (one cable at least 6 meters long)
 - 2 Microphone pre-amps (optional)
 - 1 Transient generator (clicker, wood blocks, etc.)
-

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4.2.3: Procedure

1. Mount the microphones on the stands at a comfortable height, placing them relatively close to each other. Connect a short cable to the first microphone and a long cable to the second. Connect the microphones to the pre-amps (if available). Connect the pre-amp output for microphone one (short cable) to channel one of the oscilloscope, and similarly, connect the pre-amp output for microphone two (long cable) to channel two of the oscilloscope.
2. Depress the oscilloscope's "Quick Menu" button and use the following settings: Input Coupling=AC, Input Impedance=1M, Bandwidth=20MHz. Set the Trigger Source to Channel One.
3. Adjust the oscilloscope time base (Horizontal Scale) to approximately 1 millisecond per division and the amplitude (Vertical Scale) to 5 mV per division if no pre-amps, and 100 mV otherwise. Position the Trigger Start Position toward the left edge of the display (this is the little orange triangle at the top of the grid; move it using the Horizontal Position knob).
4. Position the transient generator close to the microphones and equally distant from them. Generate a transient while observing the oscilloscope display. Adjust the vertical sensitivity scale so that the waveform peaks are seen clearly.
5. Using the sample capture/freeze ability of the oscilloscope (the "single shot" button on the extreme right side) adjust the Trigger Level control so that a transient triggers the oscilloscope. This will create a "freeze frame" of the transient events recorded by the microphones. This may take some trial and error. (Generate a transient and decrease the Trigger Level until the transient is captured. If the level is set too low, false triggers will occur on random sounds.)
6. With the oscilloscope set properly, generate a transient and examine the waveforms on the oscilloscope.
7. Adjust the Vertical Position of the two waveforms so that the starting points are visible clearly. Record the time delay between channel one and channel two in Table 1. If the delay is considerably less than one millisecond, leave the velocity column blank. If not, make sure that the transient device is located equal distances from the microphones and try again.
8. Move the second microphone to a new position at least a few meters away from the first microphone.
9. Measure the distance between the two microphones and record in the first column of Table 1.
10. Set the Horizontal Scale to 2 milliseconds per division.
11. Generate a transient very close and somewhat to the side of the first microphone. Examine the waveforms on the oscilloscope. If the second channel transient is beyond the right edge of the display, increase the Horizontal Scale and try again. The Vertical Scale (or pre-amp gain) for the second microphone may need to be increased in order to see the transient waveform.
12. Measure the time delay between the two channels and record in Table 1. Based on this time and the separation recorded in column one, compute the velocity of sound and record in Table 1.
13. Repeat steps 8 through 12 for two other microphone separations. One of them should be at least 6 meters.

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4.2.4: Data Tables

Table 1

Separation	Time Delay	Velocity	Comments
Equidistant			

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4.2.5: Questions

1. What is the purpose of initially setting the microphones next to each other?
 2. Is the time delay constant, proportional, or inversely proportional to the separation distance?
 3. Is the velocity of sound constant, proportional, or inversely proportional to the separation distance?
 4. In general, if this experiment had been repeated outside on a very cold day, would the time delays have been longer, shorter, or the same for the distances used?
-

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CHAPTER OVERVIEW

4.3: Simple Harmonic Motion

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4.3.1: Introduction

The simple harmonic motion is examined in this exercise through the observation of a simple pendulum and a mass-loaded spring. A pendulum is an example of simple harmonic motion. For small displacements of the mass relative to the length of the pendulum, and assuming that the weight of the suspending rod or wire is negligible, the frequency of oscillation is

$$f = \frac{1}{2\pi} \sqrt{\frac{g}{l}}$$

where f is the frequency in Hertz, g is the gravitational attraction (9.8 m/s^2 on Earth) and l is the length of the pendulum in meters. Note that longer pendulums produce a lower frequency of oscillation and that mass does not affect the frequency.

For the mass-loaded spring, the frequency of oscillation is

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

where f is the frequency in hertz, k is the spring constant in kilograms per second squared (higher values indicate a stiffer spring) and m is the suspended mass in kilograms. Note that a stiffer spring produces a higher frequency of oscillation and that a larger mass produces a lower frequency.

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4.3.2: Equipment

- 1 Suspension arm
 - 1 Meter stick
 - 1 Length of string, approximately 1.5 meters
 - 1 Metric hooked mass set
 - 1 Lab-quality spring ($k \approx 10 \text{ N/m}$)
 - 1 Stopwatch
-

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4.3.3: Diagrams



Figure 1



Figure 2

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4.3.4: Procedure

Part A: Pendulum

1. Clamp the suspension arm to the side of the bench as shown in Figure 1. At one end of the string, tie a loop leaving over one meter of string dangling free. Hook on the 20 gram mass.
2. From the center of the mass, measure along the string to a point one meter away. Wrap the remaining string around the horizontal arm and suspend the mass away from any obstruction.
3. Move the mass horizontally from its resting position about one-tenth the length of the string. Let go of the mass and time how long it takes to complete 30 back-and-forth swings. Record this value in the first column of Table 1. Based on this value, compute the frequency of oscillation and record that value in the second column of Table 1. Also, record the theoretical value (predicted by formula) in the third column and place any comments or observations in the fourth column.
4. Repeat steps 2 and 3 above, first using a 0.5 meter length and then a 0.25 meter length, recording the appropriate values in Table 1.
5. Copy the values in the first row (1 meter) of Table 1 to the first row (20 grams) of Table 2.
6. Replace the 20 gram mass with a 50 gram mass.
7. Once again, measure along the string one meter away from the center of the mass. Pinch the string at this point and suspend the mass away from any obstruction.
8. Move the mass horizontally from its resting position about one-tenth the length of the string. Let go of the mass and time how long it takes to complete 30 back-and-forth swings. Record this value in the first column of Table 2. Based on this value, compute the frequency of oscillation and record that value in the second column of Table 2.
9. Repeat steps 7 and 8 above using a 100 gram mass in place of the 50, recording the appropriate values in Table 2.

Part B: Spring

10. Attach the spring to the arm so that it hangs vertically as shown in Figure 2 and attach a 200 gram mass to the bottom.
11. Deflect the mass downward and release. Caution: do not over stretch the spring so that the mass flies upward past the spring's fully compressed position! Time how long it takes to complete 30 up-and-down cycles and record in column one of Table 3. Based on this value, compute the frequency of oscillation and record the value in the second and third columns of Table 3. Again, theory and observations go in the third and fourth columns.
12. Repeat step 11 using a 300 gram total mass and then a 500 gram mass.

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4.3.5: Data Tables

Table 1

Length	Time	Frequency (Exp)	Frequency (Theory)	Comments
1 meter				
0.5 meter				
0.25 meter				

Table 2

Mass	Time	Frequency (Exp)	Frequency (Theory)	Comments
20 grams				
50 grams				
100 grams				

Table 3

Mass	Time	Frequency (Exp)	Frequency (Theory)	Comments
200 grams				
300 grams				
500 grams				

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4.3.6: Questions

1. What is the affect of changing pendulum length on the frequency of motion?
 2. What is the affect of changing mass on the pendulum's frequency of motion?
 3. What is the affect of changing mass on the spring's frequency of motion?
 4. Based on established theory, if this exercise had been repeated on the moon, would you expect the frequencies noted in Table 1 to be higher, lower, or the same?
 5. What are the some of the possible sources of experimental error in this exercise and how might they be reduced?
-

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CHAPTER OVERVIEW

4.4: Tensioned String

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4.4.1: Introduction

A tensioned string is a classic example of controlled vibration which may create waveforms with many overtones or harmonics. This may result in a waveform considerably more complex in appearance than a simple sine wave although it will have a discernable period. Pythagoras studied the variables in the system circa 500 BCE and made important contributions to the science behind Western musical scales. The frequency of oscillation of a tensioned string is

$$f = \frac{1}{2l} \sqrt{\frac{T}{u}}$$

where f is the frequency in hertz, T is the tension in kilogram meters per second squared (newtons), u is the mass per unit length of the string in kilograms per meter, and l is the vibrating length of the string in meters. In this experiment, the tension, T , is simply the product of a suspended mass (kilograms) times the acceleration due to gravity (9.8 meters per second squared). That is, tension is a force and force is equal to mass times acceleration. Note that longer strings and more massive strings produce a lower frequency of oscillation and that increased tension increases frequency.

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4.4.2: Equipment

1 Meter stick

3 Lengths of varying gauge steel piano wire, approximately 1.2 meters each, or guitar/bass strings

1 Metric hooked mass set

1 Tensioned string apparatus

1 Magnetic pickup

1 Oscilloscope

1 Microphone pre-amp

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4.4.3: Diagram



Figure 1

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4.4.4: Procedure

1. Connect the channel one output of the mic pre-amp to channel one of the oscilloscope with a BNC to BNC cable. Connect the magnetic pickup to the channel one input of the mic pre-amp with an alligator clip to BNC cable. Turn on the mic pre-amp and set the gain to 3/4ths maximum. Turn on the oscilloscope and select the *Quick Menu* button. For initial settings, set *Bandwidth* to 20 MHz instead of Full, set the *Time Base* to 10 milliseconds per division and the *Amplitude* to 50 millivolts per division.
2. Referring to Figure 1, connect one end of the first wire to the hook on the back of the apparatus. Feed the wire over the groove on top of the adjustable stop piece, over the pulley at the far end, and leaving the other end of the wire dangling free.

Variation of Mass

3. Adjust the movable stop of the apparatus (an Allen wrench may be required) so that the *center* of the stop is 1 meter away from the center of the pulley opposite.
4. Hook on the 1000 gram mass and position the pickup just below the center of the string (i.e., about 0.5 meters from the pulley or stop). There should only be about 5 mm (0.2 inches) between the string and the pickup.
5. Pluck the string and watch the waveform on the oscilloscope. After the initial transient you should see a fairly repeatable wave shape, although it may not appear perfectly sinusoidal. You can “freeze” the image by hitting the *Capture/Single Shot* button. Determine the time for one cycle based on the *Time Base* setting and the number of divisions in one cycle. The *Vertical Measurement Cursors* can make this job a little easier. Compute the frequency of oscillation and record that value in the first column of Table 1. Alternately, if fairly clean waveforms can be produced consistently, the *Frequency Measurement Function* of the oscilloscope may be used. Also, compute the theoretical frequency value and place it in the second column. Place any comments or observations in the third column.
6. Repeat steps 4 and 5 above, first using 1500 grams and then 2000 grams, recording the appropriate values in Table 1.
7. Copy the values in the middle row (1500 grams) of Table 1 to the first row (1 meter) of Table 2.

Variation of Length

8. Apply 1500 grams total to the end of the wire.
9. Reposition the stop so that it is 0.5 meters from the center of the pulley and re-position the pickup so that it remains centered along the length of the wire. Pluck the string, determine and record the frequency as per step 5, recording the result in the second row of Table 2.
10. Reposition the stop so that it is 0.25 meters from the center of the pulley and re-position the pickup so that it remains centered along the length of the wire. Pluck the string, determine and record the frequency as per step 5, recording the result in the third row of Table 2.
11. Copy the values in the middle row (.5 meters) of Table 2 to the first row (gauge one) of Table 3.

Variation of Wire Gauge (mass per unit length)

12. Return the stop to 0.5 meters and replace the wire with another gauge wire (or guitar/bass string as available). Configure it as indicated in step 2 and hook on 1500 grams. Position the pickup mid-wire again.
13. Pluck the string and determine the frequency, recording the result in the second row of Table 3.
14. Repeat steps 12 and 13 using the third wire gauge, recording the results in the third row of Table 3.
15. Using the final setup, move the pick up to various positions along the wire, plucking at each new location. Note how the wave shape changes at each position.

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4.4.5: Data Tables

Table 1 (one meter length/wire gauge 1)

Mass	Frequency (Exp)	Frequency (Theory)	Comments
1000 grams			
1500 grams			
2000 grams			

Table 2 (1.5 kg mass/wire gauge 1)

Length	Frequency (Exp)	Frequency (Theory)	Comments
1 meter			
0.5 meter			
0.25 meter			

Table 3 (0.5 meters/1.5 kg)

Wire Gauge	Frequency (Exp)	Frequency (Theory)	Comments
One			
Two			
Three			

Comments/Sketches Regarding Wave Shape Versus Pickup Position:

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4.4.6: Questions

1. What is the affect of changing wire length on the frequency?
 2. What is the affect of changing mass on the frequency?
 3. What is the affect of changing wire gauge on the frequency?
 4. Based on established theory, if this exercise had been repeated on the moon, would you expect the frequencies noted in Table 3.1 to be higher, lower, or the same? What about Tables 2 and 3?
 5. What are the some of the possible sources of experimental error in this exercise and how might they be reduced?
 6. What effect (if any) does the pickup position have on the wave shape?
-

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CHAPTER OVERVIEW

4.5: Resonant Pipes

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[4.5.2: Equipment](#)

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4.5.1: Introduction

A pipe closed at one end will have a natural resonant frequency that is inversely proportional to its length. Such a pipe can support one quarter wavelength. Therefore, its fundamental resonant frequency will be:

$$f = \frac{\nu}{4l}$$

where f is the frequency in Hertz, ν is the velocity of sound in air (roughly 343 meters per second), and l is the length of the tube in meters. Pipes closed at one end will produce an odd harmonic sequence, that is, besides the strong fundamental they will also produce smaller amounts of three times the fundamental, five times the fundamental, seven times the fundamental and so on. These additional harmonics give the pipe its characteristic sound or timbre. Ideally, increased length decreases frequency and the diameter of the tube is inconsequential. In a more precise analysis, the diameter does play a minor role by slightly increasing the effective length of the tube as the diameter grows. The impact of this can be computed via an “end correction factor” which states that the effective length is increased by an additional 0.6 times the pipe’s inside radius (.3 times its diameter). For slender pipes this effect will shift the frequency by only a few percent or less.

$$f = \frac{\nu}{4(l + 0.6r)}$$

If excessive force of air is used, it is possible to strongly excite the third harmonic while suppressing the fundamental. The pipe will appear to resonate at three times the frequency predicted by the formula.

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4.5.2: Equipment

1 Measuring tape

Several pieces of PVC or similar pipe 10 to 20 cm in length and 1 to 2 cm in diameter

1 Oscilloscope

1 BNC to BNC cable

1 Microphone with cable

1 Microphone pre-amp

Sanitizing wipes

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