Instructions
Demonstrations
Experiments
Sample Data

Instruction Manual

No. 012-08678A

Sine Wave Generator

WA-9867

PASCO®

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Contents

Sine Wave Generator

Model No. WA-9867

Included Equipment	Replacement Part Number
Sine Wave Generator	WA-9867
Power Supply	540-057

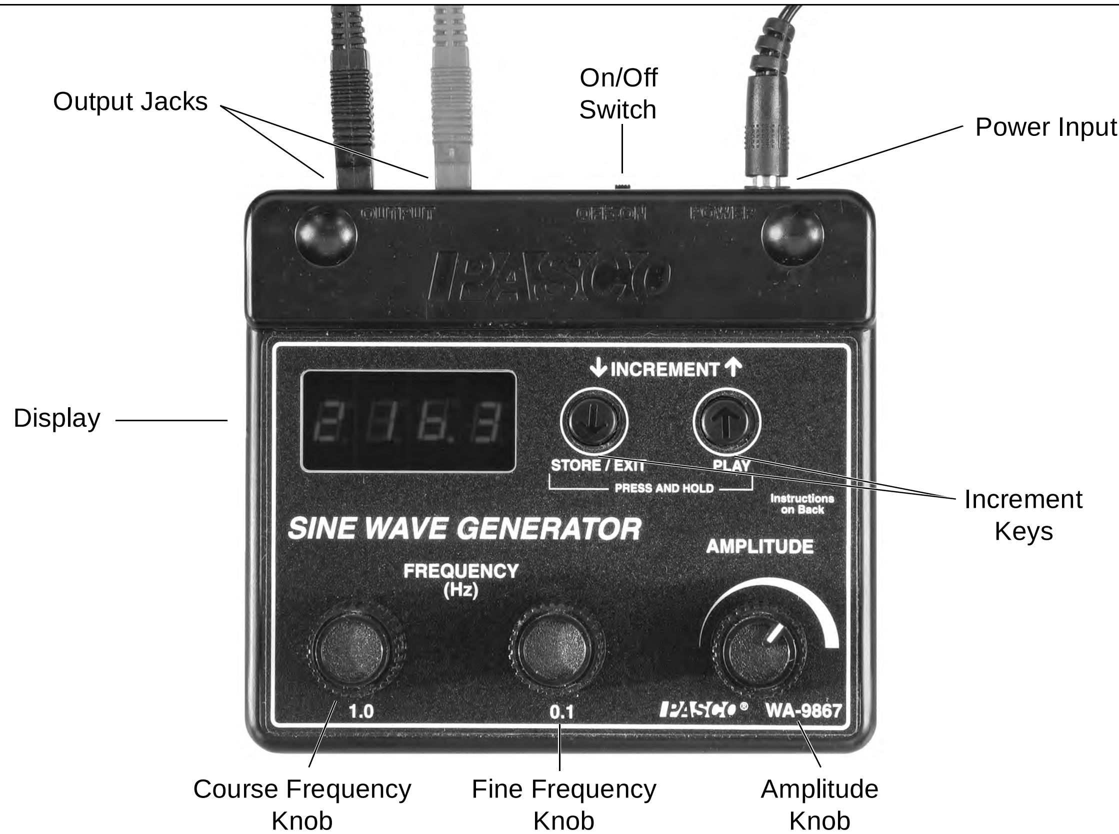
Suggested Accessories	Model Number
String Vibrator	WA-9858
Economy Wave Driver	WA-9854
Mechanical Wave Driver	SF-9324
Open Speaker	WA-9900
Economy Resonance Tube	WA-9495
Banana Patch Cords	SE-7123

Introduction

The PASCO Sine Wave Generator supplies adjustable-frequency AC power for applications such as driving speakers, wave drivers and string vibrators. The digital display and easy-to-use frequency and amplitude controls make this unit ideal for student labs.

The additional features of Auto Play and Advanced Mode with Record and Playback enhance classroom demonstrations and permanent displays requiring automated signal variation.

The Sine Wave Generator outputs AC power at up to about 10 volts amplitude (20 V peak-to-peak) and 1 amp. The output frequency, adjustable in increments of 0.1 Hz, ranges from 1 Hz to 800 Hz.



Setup

Input Power

Connect the included power supply to the power input of the Sine Wave Generator. Slide the ON/OFF switch to the right to turn it on.

Output Power

Connect a device such as a speaker or string vibrator to the output jacks of the Sine Wave Generator with a pair of 4 mm banana patch cords. Both jacks produce AC signals with opposite phases, so polarity is not important. (Note that the outputs do not float with respect to ground.)

If the Sine Wave Generator is connected to a short-circuit, the unit's short-circuit protection will shut off the output. Remove the short and cycle the input power to restore it.

Mounting and Storage

You can use the built-in clamp on the back of the unit to mount the Sine Wave Generator on a vertical rod, as shown. Rod mounting makes the display more visible for demonstrations and allows you to position the controls conveniently when you set up an experiment.

For storage, recessed dimples in the top of the case align with the feet on the bottom, allowing several units to be stacked as shown.

Operation

In addition to the description given here, there is a complete operational flow chart on page 10.

Manual Control

Amplitude

Adjust the amplitude of the output signal with the Amplitude knob. The amplitude range is approximately 0 V to 10 V.

Frequency

Set the output frequency with the Coarse and Fine Frequency knobs (labeled “1.0” and “0.1”). The LED display indicates the frequency to 0.1 Hz resolution. When the Sine Wave Generator is first turned on, it outputs the default frequency of 100 Hz. You can adjust the output signal from 1 Hz to 800 Hz.

The Frequency knobs are mechanical encoders with 24 discrete detents, or clicks, per revolution. One click of the Fine knob changes the frequency by 0.1 Hz. One click of the Coarse knob changes the frequency by 1.0 Hz if the knob is turned slowly, or 4.0 Hz if the knob is turned quickly. This allows you to change the frequency more quickly over a large range.

You can also use the Up and Down Increment keys to change the frequency. Each quick press of the Up or Down key changes the frequency by the stored increment. By default the increment is 100 Hz. To change the stored increment, see the Increment Keys section below. (If you press and hold the Increment keys, a different function will occur, so only use *quick* presses to change the frequency.)

This following sections describe how to change the stored frequency increment and program the Sine Wave Generator to play automatic sequences of notes. If you would like to skip to some practical demonstrations, see the Applications section on page 11.

Increment Keys

The Up and Down arrow keys have multiple functions. The Increment function is activated by a single quick press and release of either key. Other functions are activated when you press and *hold* the keys. For example, to implement the Play function you would press and *hold* the Up arrow key for about 1 second. The instructions may read, “press and *hold* the Play key,” or, “press the Up Increment key.” Both refer to the same key, but different functions. The labels below the keys (Store/Exit and Play) indicate the press-and-hold functions of the keys.

Changing the Output Frequency by the Stored Increment

Each *quick* press of the Up or Down Increment key changes the output frequency by the amount stored as the increment. The default increment (when unit is initially turned on) is 100 Hz. Thus, a single press of the Up Increment key will add 100 Hz to the output frequency. Try this:

1. Turn the Sine Wave Generator on (if it is already on, turn it off for a second, then back on). The initial output frequency is 100 Hz.

2. Press the Up Increment key. The frequency changes to 200 Hz. Press it again and it changes to 300 Hz. Press the Down Increment key and the frequency changes back to 200 Hz.

3. Use the Frequency knobs to change the frequency to 220 Hz.

4. Press the Up Increment key; the frequency changes to 320 Hz.

5. Press the Up Increment key several more times so that the output is 720 Hz. Additional presses of the Up Increment key will do nothing because the output will not exceed 800 Hz.

Setting the Stored Increment

The harmonics of a resonating device (such as a vibrating string or tube) are usually spaced at equal frequency increments. It is useful to set the Sine Wave Generator's stored increment to match your device.

The label below the Up arrow key reads Store/Exit. When you press and hold this key, it will function as a Store key; the stored increment will change to the value on the display (which is the output frequency). Try this:

1. Use the Increment keys and the Frequency knobs to set the output to 120 Hz.

2. Press and *hold* the Store key. After 1 second the display will blink and you can release the key. The stored increment is now 120 Hz.

3. Press the Up Increment key a few times; the frequency changes by 120 Hz with every press.

This value will remain stored until a new value replaces it or the unit is turned off.

Auto Play

In Auto Play mode you can program the Sine Wave Generator to scan automatically through the harmonics of a device.

Setup

The label below the Up arrow key reads Play. When you press and *hold* it, this key will start automatic play. Try this:

1. Set the stored increment to 120 Hz (as described above).

2. Use the Amplitude knobs to change the output frequency to 60 Hz.

3. Press and *hold* the Play key. The display will blink to show you that Auto Play has started, and you can release the key.

4. The Sine Wave Generator will play the starting note (60 Hz), then increment to the next notes (180 Hz, 300 Hz, 420 Hz, etc.), playing each note for 1.5 seconds. You can use the Amplitude knob to adjust the output.

Duration of Each Note

While in Auto Play mode, you can use the Frequency knobs to change the duration of each note. By default, each note is played for 1.5 seconds. If you turn the Course (1.0) knob one click clockwise, it will increase the duration by 1 second. The display will switch over to show the duration (in seconds), and then switch back to showing the frequencies. One click of the Fine (0.1) knob will change the duration by 0.1 second. The duration can be set from 0.1 to 99.9 seconds.

Wrap Around

Auto Play will continue to increment the frequency until it reaches the maximum (up to, but not over 800 Hz); then it will wrap around and start the sequence again. To make Auto Play wrap around at a lower frequency, press and *hold* the Play key when the sequence is at the highest note that you want. (The display will blink after 1 second to indicate that you can release the key.)

Exit Auto Play

To stop Auto Play, press and *hold* the Store/Exit key. (The display will blink after 1 second to indicate that you can release the key.) The Sine Wave Generator will return to normal mode, and the output frequency will return to the original starting frequency.

Advanced Mode: Record and Playback

In Advanced Mode you can set, store and play back a sequence of up to 80 notes. The Sine Wave Generator will record the frequency and *amplitude* of each note. Advanced Mode is especially useful when demonstrating resonance in vibrating strings because it allows you to set the optimal amplitude and frequency for each harmonic.

This mode is a hidden sub-layer so as to not confuse the student with extra complexity in normal lab use. It is intended for the teacher's use in demonstrations. Although it is "hidden", it is easily accessible and straightforward to use.

Entering Advanced Mode

Press and hold *both* arrow keys simultaneously (as shown) until the display changes to indicate the number of recorded notes. If no sequence is stored it will display "0."

After entering Advanced Mode there are 3 options:

Exit: Press and *hold* the Store/Exit key to leave Advanced Mode and return to normal mode.

Play the Stored Sequence: Press and *hold* the Play key. The Sine Wave Generator will enter Playback Mode and play the sequence of recorded notes. (If there is no recorded sequence, this action will exit Advanced Mode.)

Enter Record Mode: Press and hold *both* keys simultaneously again to enter Record Mode. The display will show "0" (to denote that it has cleared out the previously stored sequence) and begin to flicker to indicate that the unit is in Record Mode.

Record a Sequence of Notes

In Record Mode the display will always flicker. When you enter Record Mode, the display shows the output frequency. Connect the apparatus (such as a string vibrator with a string) to the Sine Wave Generator so that you can tune the frequency and amplitude for each harmonic.

1. Enter Record Mode (see above).

2. Set the frequency *and amplitude* of the first note in the sequence (usually the fundamental resonance frequency of the apparatus).

The Frequency knobs and the Increment keys function as normal. Use only a *quick* press and release to implement the up and down increment. The increment value is what it was set to before you entered Advanced Mode.

3. Press and *hold* the Store key until the display changes; for a moment the display will show the total number of stored notes, then return to showing the frequency.

4. Adjust the frequency and amplitude for the next note in the sequence and return to step 3.

5. After you have stored the entire sequence of notes, press and *hold* the Play key until the display stops flickering. The Sine Wave Generator will switch to Playback Mode and begin to play the sequence that you have recorded.

While you are recording a sequence, be careful not to make a mistake. There is no way to edit a note in the sequence after it has been stored. When you enter Record Mode, all previous notes are erased and you start over. Once you have stored a note, you can not change or erase it.

Playback of Stored Notes

With the Sine Wave Generator in Playback Mode and playing the stored sequence, you have several options:

Amplitude: If you turn the Amplitude knob all the way up, the unit will play back the stored notes exactly as you recorded them. If you turn the knob down, it decreases all of the stored notes by the same proportion.

Duration: You can use the Frequency knobs to change the duration of every note. The default duration is 1.5 seconds. The Course (1.0) knob changes the duration by 1 second per click, the Fine (0.1) changes the duration by 0.1 second per click. If you exit Advanced Mode and return later, the Sine Wave Generator will remember the previous duration setting.

Pause: A *quick* press of the Down arrow key pauses the playback of the stored sequence. To resume playback, press and *hold* Play until the display blinks.

While paused, a quick press of the Up or Down arrow key will cause the next or previous note in the sequence to play.

While paused, you can use the Frequency knobs to vary the output frequency. This is useful to show what happens when the driving frequency is slightly off resonance. Changing the frequency with the knobs while playback is paused does *not* change the stored notes.

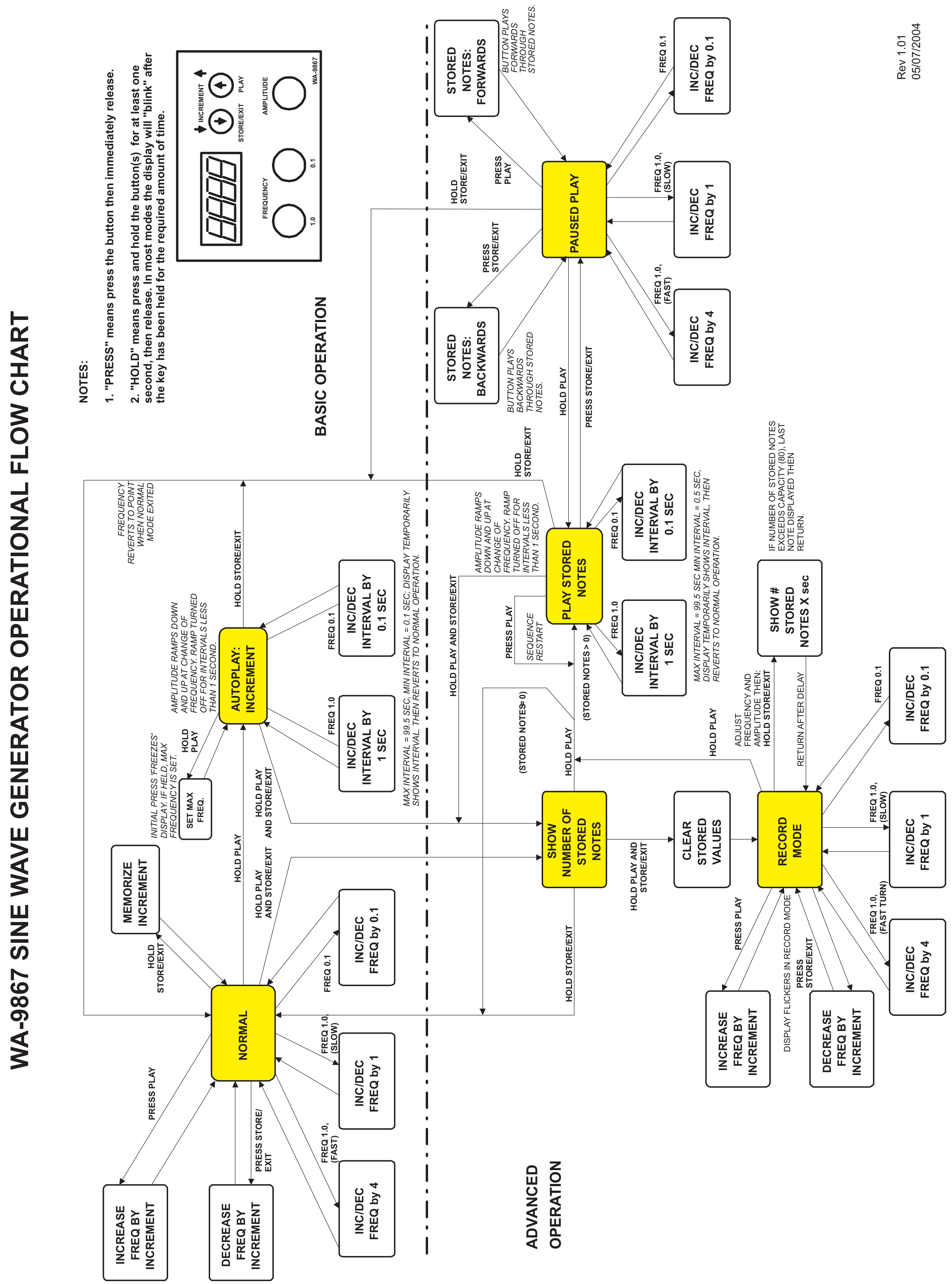
Sequence Start-over: When the last stored note has been played, the Sine Wave Generator wraps around and starts over with the first note. At any time during play mode, a *quick* press of the Up arrow key will cause the sequence to start over with the first note.

Stop Playback: Press and *hold* the Store/Exit key to return to normal mode. The output frequency will be set to the stored increment.

The sequence remains in storage. You can go back to Advanced Mode and play the sequence again, even if you turned the unit off and unplug it in the interim.

Specifications

Frequency	1 to 800 Hz Adjustable in 0.1 Hz increments
Output	DC coupled push-pull Short-circuit protected
Amplitude	0 to 10 V peak (approx.)
Current	>1 A into 8 Ω load
Memory	Up to 80 stored notes
Display	4 digit LED
Input Power	100–240 VAC, 50/60 Hz
Dimensions	12 × 11 × 5 cm (not including separate power supply)


WA-9867 SINE WAVE GENERATOR OPERATIONAL FLOW CHART
NOTES:
1. "PRESS" means press the button then immediately release.
2. "HOLD" means press and hold the button(s) for at least one second, then release. In most modes the display will "blink" after the key has been held for the required amount of time.
FREQUENCY
1.0
0.1
AMPLITUDE
INCREMENT
STORE/EXIT
PLAY
WA-9867
BASIC OPERATION
ADVANCED OPERATION
NORMAL
INCREASE FREQ BY INCREMENT
DECREASE FREQ BY INCREMENT
PRESS PLAY
PRESS STORE/ EXIT
INC/DEC FREQ by 4
INC/DEC FREQ by 1
INC/DEC FREQ by 0.1
FREQ 1.0, (FAST)
FREQ 1.0, (SLOW)
FREQ 0.1
MEMORIZE INCREMENT
HOLD STORE/EXIT
HOLD PLAY
HOLD PLAY AND STORE/EXIT
SET MAX FREQ.
INITIAL PRESS 'FREEZES' DISPLAY. IF HELD, MAX FREQUENCY IS SET.
AUTOPLAY: INCREMENT
AMPLITUDE RAMPS DOWN AND UP AT CHANGE OF FREQUENCY. RAMP TURNED OFF FOR INTERVALS LESS THAN 1 SECOND.
FREQUENCY REVERTS TO POINT WHEN NORMAL MODE EXITED
HOLD STORE/EXIT
INC/DEC INTERVAL BY 1 SEC
INC/DEC INTERVAL BY 0.1 SEC
FREQ 1.0
FREQ 0.1
MAX INTERVAL = 99.5 SEC, MIN INTERVAL = 0.1 SEC; DISPLAY TEMPORARILY SHOWS INTERVAL, THEN REVERTS TO NORMAL OPERATION.
HOLD PLAY AND STORE/EXIT
SHOW NUMBER OF STORED NOTES
(STORED NOTES = 0)
(STORED NOTES > 0)
HOLD PLAY
HOLD STORE/EXIT
PLAY STORED NOTES
PRESS PLAY
SEQUENCE RESTART
AMPLITUDE RAMPS DOWN AND UP AT CHANGE OF FREQUENCY. RAMP TURNED OFF FOR INTERVALS LESS THAN 1 SECOND.
INC/DEC INTERVAL BY 1 SEC
INC/DEC INTERVAL BY 0.1 SEC
MAX INTERVAL = 99.5 SEC MIN INTERVAL = 0.5 SEC, DISPLAY TEMPORARILY SHOWS INTERVAL, THEN REVERTS TO NORMAL OPERATION.
HOLD STORE/EXIT
HOLD PLAY
PRESS STORE/EXIT
PAUSED PLAY
STORED NOTES: BACKWARDS
STORED NOTES: FORWARDS
BUTTON PLAYS BACKWARDS THROUGH STORED NOTES.
BUTTON PLAYS FORWARDS THROUGH STORED NOTES.
PRESS STORE/EXIT
HOLD STORE/EXIT
PRESS PLAY
INC/DEC FREQ by 4
INC/DEC FREQ by 1
INC/DEC FREQ by 0.1
FREQ 1.0, (FAST)
FREQ 1.0, (SLOW)
FREQ 0.1
HOLD PLAY AND STORE/EXIT
CLEAR STORED VALUES
RECORD MODE
HOLD PLAY
ADJUST FREQUENCY AND AMPLITUDE THEN: HOLD STORE/EXIT
RETURN AFTER DELAY
SHOW # STORED NOTES X sec
IF NUMBER OF STORED NOTES EXCEEDS CAPACITY (80), LAST NOTE DISPLAYED THEN RETURN.
PRESS PLAY
DISPLAY FLICKERS IN RECORD MODE
PRESS STORE/EXIT
INCREASE FREQ BY INCREMENT
DECREASE FREQ BY INCREMENT
INC/DEC FREQ by 4
INC/DEC FREQ by 1
INC/DEC FREQ by 0.1
FREQ 1.0, (FAST TURN)
FREQ 1.0, (SLOW)
FREQ 0.1
Rev 1.01
05/07/2004

Applications

Open Resonance Tube

The resonance tube shown here has both ends open and a fundamental resonance frequency of 120 Hz. It is set up to be driven by a speaker and Sine Wave Generator. (Note the position and angle of the speaker relative to the end of the tube.)

There are two ways to use the Auto Play feature to demonstrate resonance. With the first method, the Sine Wave Generator steps through a series of resonance frequencies. With the second method, it scans slowly through a frequency range encompassing one resonance frequency.

Method 1: Step Through the Harmonics

1. Using the Frequency knobs, set the output to the fundamental resonance frequency of the tube (120 Hz in this case). Listen carefully while adjusting to determine the optimal driving frequency.

2. Press and *hold* the Store/Exit key to store the increment as 120 Hz (or whatever the current output frequency is).

3. Press and *hold* the Play key to start Auto Play. The speaker will play 120 Hz, 240 Hz, etc., up to 720 Hz, then repeat.
4. You will notice that the tube does not resonate well above a certain frequency. When the sequence reaches the highest note that you want, press and *hold* the Play key. Thereafter, the sequence will wrap around after that note.
5. Adjust the amplitude of the driving signal with the Amplitude knob.
6. Adjust the duration of each note with the Course (1.0) and Fine (0.1) Frequency knobs.
7. To stop Auto Play, press and hold the Store/Exit key.

Method 2: Scan Across the Fundamental Resonance

1. Using the Frequency knobs, turn the frequency down to 1 Hz. (If you turn the Coarse knob slowly, the frequency changes by 1 Hz per click; if you turn it faster, the frequency changes by 4 Hz per click.)
2. Press and hold the Store/Exit key to store the increment as 1 Hz.
3. Use the Frequency knobs again to set the frequency to 110 Hz.
4. Press and *hold* the Play key to start Auto Play. When the frequency reaches 130 Hz, press and *hold* the Play key again to make the frequency wrap around and repeat.
5. Use the Frequency knobs to adjust the duration of each note to about 0.5 seconds.

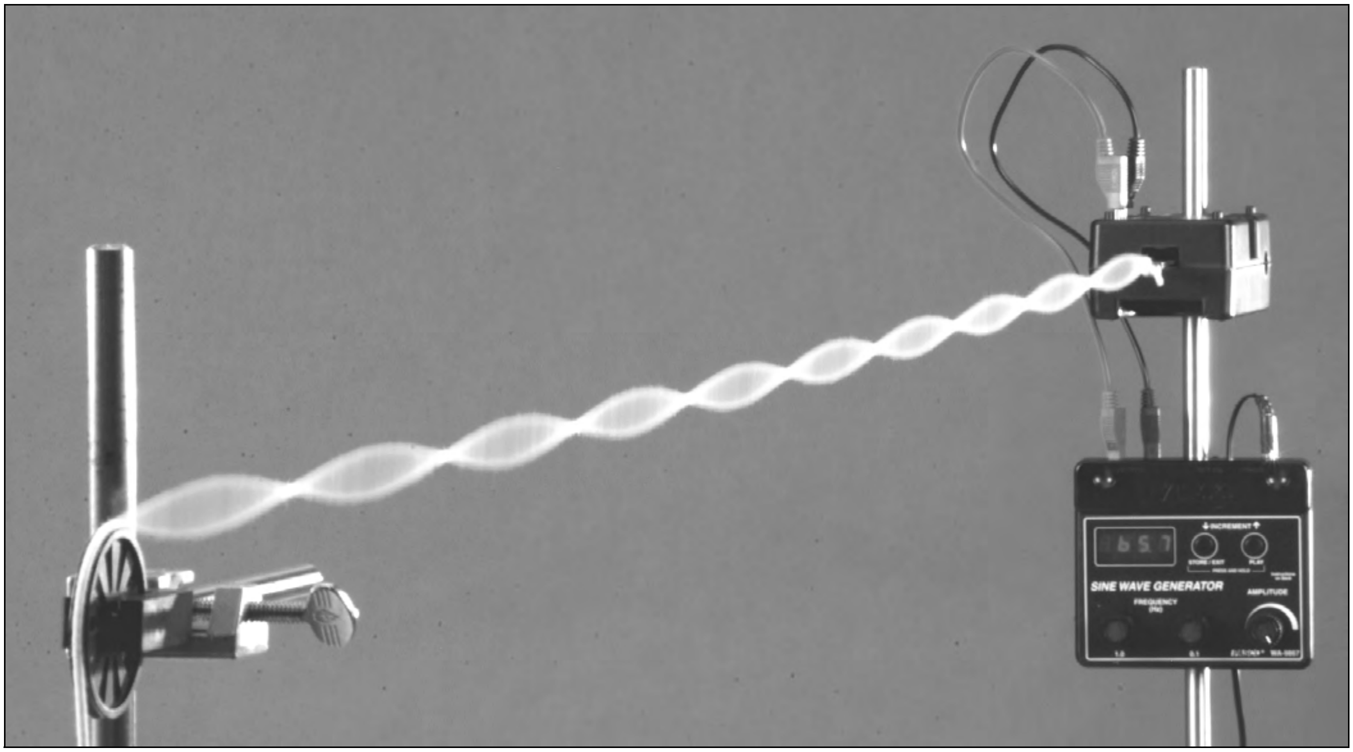
The Sine Wave Generator will now repeatedly scan across the resonance at 120 Hz. Remove the tube to show that the sound level from the speaker is constant, then put the tube back in place to show how much louder it gets each time the frequency is near resonance.

Closed Resonance Tube

1. Replace the tube from the previous demonstration with a tube that has one closed end, one open end, and a fundamental resonance of 60 Hz.
2. Use the Frequency knobs to set the output frequency to the fundamental resonance, then press and *hold* Play to make the speaker play 60 Hz, 120 Hz, 180 Hz, etc.
3. Why doesn’t the tube resonate at 120 Hz? This is a good way to demonstrate that closed pipes only play the odd harmonics.

You can also set up the Sine Wave Generator to play *only* the odd harmonics.

1. Using the frequency knobs, set the frequency to 120 Hz.
2. Press and hold the Store/Exit key to store the increment as 120 Hz.
3. Use the frequency knobs again to set the initial frequency to 60 Hz.
4. Press and *hold* the Play key; the speaker will play 60 Hz, 180 Hz, 300 Hz, etc.



Vibrating String

This automated display of a vibrating string is a good example of where the Advanced Mode is useful. With a 2 meter elastic cord and the PASCO String Vibrator (WA-9857), you can easily get a standing wave of 10 segments or more.

In this demonstration, the Sine Wave Generator scans through the resonance frequencies so that you see the string vibrate with 1, 2, 3, etc., segments. The generator is mounted vertically to display the driving frequency. Once set up, it will cycle indefinitely, making for an engaging permanent display.

For best results, use Advanced Record and Playback Mode. If you were to use the regular Auto Play mode, there are two problems that would occur. First, the optimal driving-signal amplitude for the lower harmonics would be insufficient to excite visible vibrations at the higher harmonics. Second, it would be difficult to perfectly tune a single increment value so that the driving frequencies for all 10 harmonics were exactly correct.

Both of these problems are solved with Advanced Mode, since you store both the frequency and amplitude of each note in the sequence. Because the Sine Wave Generator is working as you record the sequence, you can finely tune the driving signal for maximum effect at every harmonic.

See the Advance Mode section on page 7 for programing instructions, and the PASCO String Vibrator manual for mechanical details of the setup.

Experiment 1:
Standing Waves In Strings

Equipment	Part Number
Sine Wave Generator	WA-9867
String Vibrator	WA-9857
Braided String (inelastic, low-density)	SE-8050 or similar
Yellow Braided Cord (inelastic, higher-density)	ME-9409 or similar
Elastic Cord	Part of WA-9857, SE-9409 or similar
Banana Patch Cords (qty. 2)	SE-7123 or similar
Clamp or other device of securing the String Vibrator	SE-7286 or similar
Super Pulley	ME-9450
Mounting Rod for Super Pulley	SA-9242
Universal Table Clamp	ME-9472 or similar
Mass and Hanger Set	ME-8967 or similar
Balance	SE-8765A or similar
Tape Measure	SE-8712A or similar
Strobe (optional)	SF-9211 or similar

Introduction

The general appearance of waves can be shown by means of standing waves in a string. This type of wave is very important because most vibrations of extended bodies, such as the prongs of a tuning fork or the strings of a piano, are standing waves. In this experiment you will discover how the speed of the wave in a vibrating string is affected by the density of the string, the stretching force and the frequency of the wave.

Theory

Standing waves (stationary waves) are produced by the interference of two traveling waves, both of which have the same wavelength, speed and amplitude, but travel in opposite directions through the same medium. The necessary conditions for the production of standing waves can be met in the case of a stretched string by having waves set up by some vibrating body, reflected at the end of the string and then interfering with the oncoming waves.

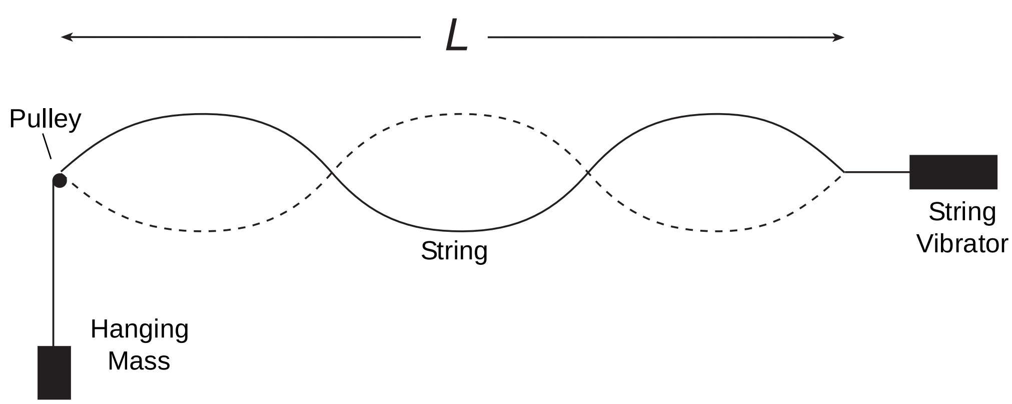
A stretched string has many natural modes of vibration (three examples are shown above). If the string is fixed at both ends then there must be a node at each end. It may vibrate as a single segment, in which case the length (L) of the string is equal to 1/2 the wavelength (λ) of the wave. It may also vibrate in two segments with a node at each end and one node in the middle; then the wavelength is equal to the length of the string. It may also vibrate with a larger integer number of segments. In every case, the length of the string equals some integer number of half wavelengths.

If you drive a stretched string at an arbitrary frequency, you will probably not see any particular mode; many modes will be mixed together. But, if the driving frequency, the tension and the length are adjusted correctly, one vibrational mode will occur at a much greater amplitude than the other modes.

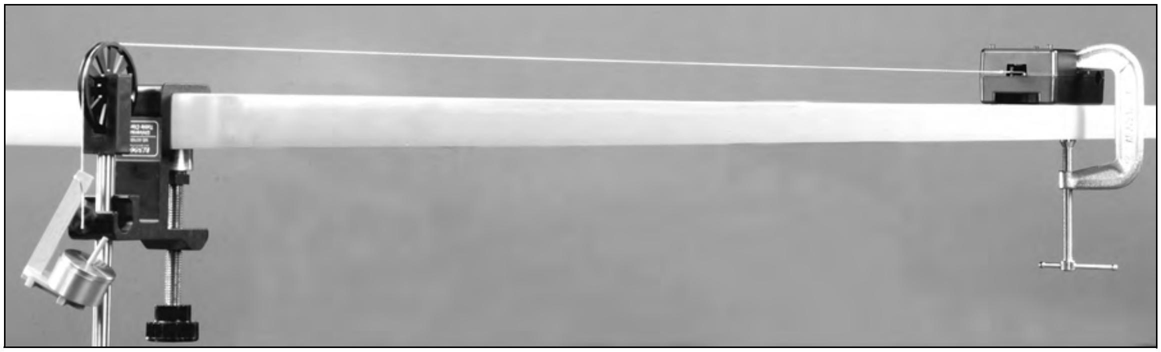
For any wave with wavelength λ and frequency f, the speed, v, is

(eq. 1) $$v = \lambda f$$

In this experiment, standing waves are set up in a stretched string by the vibrations of an electrically-driven string vibrator. The arrangement of the apparatus is shown below. The tension in the string equals the weight of the mass suspended over the pulley. You can alter the tension by changing the mass. You can adjust the amplitude and frequency of the wave by adjusting the output of the Sine Wave Generator, which powers the string vibrator.



Setup



1. As shown in the picture, clamp the Sine Wave Generator and pulley about 120 cm apart. Attach about 1.5 m of braided string to the vibrating blade, run it over the pulley, and hang about 150 g of mass from it.
2. Measure from the knot where the string attaches to the string vibrator to the top of the pulley. This is distance L. (Note that L is *not* the total length of the string, only the part that is vibrating.)
3. Turn on the Sine Wave Generator and turn the Amplitude knob all the way down (counter-clockwise). Connect the Sine Wave Generator to the string vibrator using two banana patch cords. Polarity does not matter.

Part I:
Wavelength and Frequency

Procedure

1. Set the Amplitude knob about midway. Use the Coarse (1.0) and Fine (0.1) Frequency knobs of the Sine Wave Generator to adjust the vibrations so that the string vibrates in *one* segment. Adjust the driving amplitude and frequency to obtain a large-amplitude wave, but also check the end of the vibrating blade; the point where the string attaches should be a node. It is more important to have a good node at the blade than it is to have the largest amplitude possible. However, it is desirable to have a large amplitude while keeping a good node.
2. Record the frequency. How much uncertainty is there in this value? How much can you change the frequency before you see an effect?
3. Repeat steps 1 and 2 for a standing wave with *two* segments. The string should vibrate with a node at each end and one node in the center.
4. How is the frequency of the two-segment wave related to the frequency of the one-segment wave? Calculate the ratio of the frequencies. Is the ratio what you would expect?
5. With the wave vibrating in two segments, the length of the string, L, is one wavelength ($L = \lambda$). Does it look like one wavelength? Since the string vibrates up and down so fast, it is hard to see that when one side is up, the other is down. Examine the vibration of the string

using a strobe light if one is available. Adjust the strobe frequency to be near the frequency of the Sine Wave Generator. The string will look like it is moving in slow motion.

6. Try touching the string at an anti-node. What happens? Try touching the string at the central node. Can you hold the string at the node and not significantly effect the vibration?

7. What was the wavelength when the string was vibrating in one segment? Use Equation *1* to calculate the speed of the one-segment wave.

8. Calculate the speed of the two-segment wave. How do these to values compare? Are they *about* the same? Why?

9. Adjust the frequency so that the string vibrates in *three* segments. Has the velocity changed? Does the speed of the wave depend on the wavelength and the frequency?

Further Investigations

Changing Tension

1. Adjust the frequency so that the string vibrates in two segments. Now, without changing the frequency, decrease the mass on the hanger until the string vibrates in 4 segments. (You may have to use small masses to get a good waveform. Remember that it is more important to have a good node at the end of the blade than to have the biggest amplitude possible.)

2. Record the total hanging mass, including the mass hanger. Calculate the ratio of the new mass to the original mass. Why is the ratio not 2? You will learn more about the relationship between wave velocity and string tension in Part II of this lab.

Changing Length

1. Return the mass to its original amount. Set the frequency to a value between the frequencies that produced waves of two and three segments. Adjust the frequency so that no particular standing waveform is present.

2. Unclamp the string vibrator and slowly move it towards the pulley. (Do not let go of the string vibrator without clamping it to the table again.)

3. Without changing the driving frequency or the hanging mass decrease the length of vibrating string until it vibrates in *two* segments. Adjust the position to get the best node at the blade, as before. (If the hanging mass touches the floor, reattach it to the string higher up.)

4. Measure the new wavelength and calculate the speed of the wave. Is it about the same as before? Does the speed of the wave depend on the length of the string?

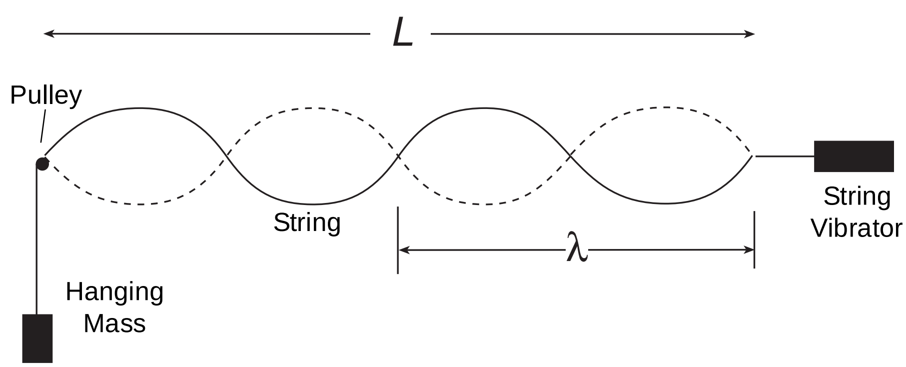
Part II:
Wave Speed and String Density

Theory

As stated in Equation *1*, the speed of any wave is related to the wavelength and the frequency. For a wave on a string, the speed is also related to the Tension (F) in the string, and the linear density (μ) of the string, as shown by

(eq. 2) $$v = \sqrt{\frac{F}{\mu}}$$

The linear density (μ) is the mass per unit length of the string. The Tension (F) is applied by the hanging a mass (m), and is equal to the weight (mg) of the hanging mass.



For this part of the experiment, you will always adjust the frequency so that the wave vibrates in *four* segments, thus the length of the string will always equal two wavelengths ($L = 2\lambda$).

In this case $F = mg$ and $L = 2\lambda$; these equations can be combined with equations *1* and *2* to show

(eq. 3) $$f^2 = \frac{4g}{\mu L^2} m$$

where:

f = driving frequency of the Sine Wave Generator
g = acceleration due to gravity
m = total hanging mass
L = length of string (vibrating part only)
μ = linear density of the string (mass/length)

Procedure

1. Clamp the String Vibrator about 120 cm from the pulley. Hang about 50 g from the string over the pulley. Measure from the knot at the vibrating blade to the top of the pulley. This is the distance L. (Note that L is *not* the total length of the string, only the part that is vibrating.)

2. Record the total hanging mass, including the mass hanger.

3. Adjust the frequency of the Sine Wave Generator so that the string vibrates in *four* segments. As before, adjust the driving amplitude and frequency to obtain a large-amplitude wave, *and* clean nodes, including the node at the end of the blade. Record the frequency.

4. Add 50 g to the hanging mass and repeat steps 2 and 3.

5. Repeat at intervals of 50 g up to at least 250 g. Record your data in a table.

6. Make a graph of Frequency-squared, f^2, versus hanging mass, m. (The units will be easier to work with later if you graph the mass in kilograms.) Is the graph linear?

7. Find the slope (including uncertainty) of the best-fit line through this data.

8. As you can determine from Equation *3*, the slope of the f^2 vs. m graph is:

$$\text{slope} = \frac{4g}{\mu L^2}$$

   From the slope of your graph, calculate the density (μ) of the string. What is the uncertainty?

9. Determine the actual density of the string by measuring the mass of a known length. If you do not have a balance readable to 0.01 g, use several meters of string.

10. Compare the density that you measured in step 8 to the actual density that you determined in step 9. Calculate the percent deviation.

$$\%\text{ Deviation} = \frac{\text{Measured} - \text{Actual}}{\text{Actual}} \times 100\%$$

Further Investigations

1. Repeat the procedure using the yellow cord. Put the data from the string and cord on the same graph to show the difference in their densities.

2. Repeat the procedure with elastic cord. The density is much larger, so put the data on a separate graph. Look carefully at the graph. Is it linear like the first two? Calculate the density using both the minimum and maximum slopes.

3. Measure how much the elastic cord stretches when you place the maximum mass on the hanger. Based on the unstretched density of the cord, and the amount that it stretches, estimate the “stretched” density of the cord. Compare this value to the densities that you calculated from your graph.

Experiment 2:
Resonance Tubes

Equipment	Part Number
Sine Wave Generator	WA-9867
Open Speaker	WA-9900 or similar
Banana Patch Cords (qty. 2)	SE-7123 or similar
Economy Resonance Tube	WA-9495
Twirlable Sound Tubes (optional)	SE-8692 (4-pack)

Introduction

In this experiment you will discover the relationship between the wavelength, wave speed and frequency of sound waves in resonance tubes. You will learn about nodes, anti-nodes and the end effect in both closed and open tubes.

Set-up

1. Turn on the Sine Wave Generator and turn the amplitude knob all the way down (counter-clockwise).

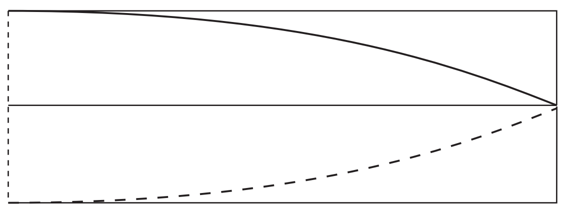
2. Connect the generator to the speaker using two banana patch cords. Polarity does not matter.

3. Place the Resonance Tube horizontally, as shown, with the speaker near the open end. Place the speaker at a 45° angle to the end of the tube, not pointed directly into it.

Part I:
Closed Tube of Variable Length

Theory

A resonating tube with one end open and the other end closed will always have a node at the closed end and an anti-node at the open end. A node represents an area where the velocity of the air is a minimum (zero), and an anti-node represents an area where the velocity of the air is a maximum. If the tube is resonating in the fundamental mode (lowest possible frequency) it will have no other nodes or anti-nodes. This is shown in the diagram below, where the curved lines represent the velocity profile of the air in the tube.



On a sine wave, the distance from one of the maxima to the next point where it crosses zero is a quarter wavelength. Thus, for a tube with one open end and one closed end, the length of the tube, L, and the wavelength, λ, are related by:

(eq. 1) $$\lambda = 4L$$

For all types of waves, the relationship between the frequency (f) and the velocity (v) of the wave is:

(eq. 2) $$v = \lambda f$$

For a resonating tube, v is the speed at which sound travels through the air in the tube, and f is the frequency of the sound. In this experiment, the sound frequency is the frequency of the Sine Wave Generator.

Combining equations *1* and *2* yields:

(eq. 3) $$L = \tfrac{1}{4} v \frac{1}{f}$$

Thus we see that the length of the tube is inversely proportional to the fundamental frequency.

Procedure

1. Extend the tube so that the scale reads 100 cm (the white tube slides inside the blue tube). Use a meter stick inside the tube to check if the scale is accurate. If the value is not correct within 0.2 cm, record the offset and compensate for this discrepancy in all future measurements.

2. Extend the tube to 120 cm. Set the Sine Wave Generator frequency to 50 Hz, and turn up the amplitude to a reasonable level.

3. Slowly increase the frequency using the coarse (1.0) knob, and listen for resonance. When you are within a few hertz of the fundamental frequency, the loudness off the sound will increase noticeably. (You will hear this resonance before the frequency reaches 100 Hz.) Using the coarse knob, adjust the frequency up and down across the resonance. Listen carefully to determine at what frequency it is loudest. Try to determine the resonance frequency to the nearest 1 Hz. Record the tube length and frequency in a table.

4. Decrease the length of the tube to 110 cm and repeat the previous step. Take data at 10 cm intervals down to a length of 50 cm. (The resonance frequency will eventually exceed 100 Hz.)

5. Make a graph of Tube Length versus Inverse Frequency (L vs.$1/f$). Note that the horizontal axis is the *inverse* of frequency.

6. Find both the slope and the y-intercept of the best-fit line through this data.

7. From Equation *3* we see that the slope of the graph is:

$$\text{Slope} = \tfrac{1}{4}\,v$$

Use the slope from your graph to calculate the speed of sound in air. Estimate the uncertainty.

8. The *actual* speed of sound depends on the temperature of the air:

$$v = 331\ \text{m/s} + 0.6\,T$$

where T is the temperature of the air in degrees Celsius. Measure the air temperature and calculate the actual speed of sound.

9. Compare your measured speed of sound from step 7 to the actual speed of sound. Calculate the percent deviation.

$$\%\ \text{Deviation} = \frac{\text{Measured} - \text{Actual}}{\text{Actual}} \times 100\%$$

10. On your graph of L vs. $1/f$, why isn't the y-intercept zero? Is the intercept negative?

A negative intercept indicates that the *effective* length of the tube is longer than the *actual* length. The anti-node at the open end of the tube is actually formed past the end, slightly outside the tube. This phenomenon is called the “end effect”. The extra end-effect length is proportional to the diameter of the tube, and can be empirically represented as

$$\text{End Effect} = 0.3 \times \text{Diameter of Tube}$$

Measure the diameter of the tube and use this equation to calculate the end effect. How does this value compare with the y-intercept of your graph?

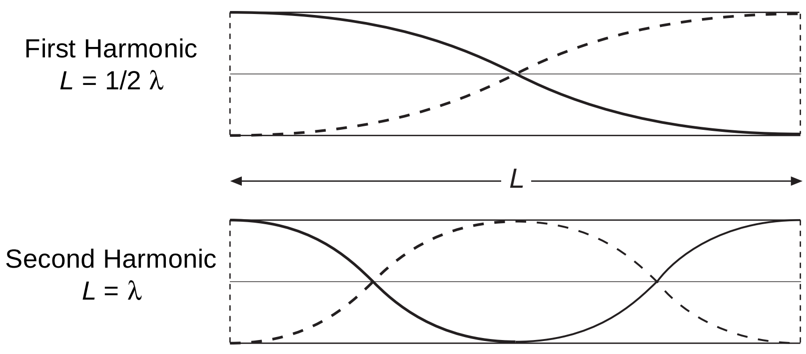
Further Investigations

1. Set the frequency to 230 Hz, and extent the tube to 120 cm. Without changing the frequency, slowly shorten the tube until you hear resonance. Adjust the tube length back and forth across the resonance to locate the position of the node. Record the position of the node (which is the length of the tube).
2. Without changing the driving frequency, continue to shorten the tube until you hear resonance again. Record the position of this node.
3. The distance between the two resonance positions (the distance between adjacent nodes) is $1/2\ \lambda$. Why?
4. Calculate the wavelength from the distance between the nodes. From this wavelength and the frequency of the Sine Wave Generator, calculate the speed of sound. How does it compare with your earlier value?
5. Draw a companion sketch of the waveform diagram on page 22, showing *two* nodes and the same frequency. Remember that there must be a node at the closed end and an anti-node at the open end.   Hint: the tubes in the two drawings should not be the same length, but the wavelengths are the same.

Part II:
Open and Closed Tubes of Fixed Length

Theory

A resonating tube with both ends open will always have an anti-node at either end, and at least one node in between. The number of nodes is related the wavelength and the harmonic. The first harmonic (or fundamental) has one node, the second harmonic has two, etc., as shown here:



At higher harmonics, the frequency is higher and the wavelength is shorter (length of tube does not change).

Procedure

1. Slide the inner tube all the way out, and separate it from the outer tube. Use only the outer blue tube with two open ends.

2. Set up the Sine Wave Generator and the speaker as before. Start with the frequency at 50 Hz and slowly increase it using the coarse (1.0) knob. Find the frequency of the fundamental (to the nearest 1 Hz) as you did before. Why is the frequency of the fundamental higher for the open tube than it was for the closed tube?

3. Calculate the wavelength from the frequency and the speed of sound. Use Equation *2*, and the speed of sound that you found in Step 8 of Part I. (You do not need to know the length of the tube).

   Look at the diagram of the fundamental (first harmonic), and use that information to calculate the *effective length* of the tube.

4. Use a meter stick to measure the actual length of the tube. How does it compare to the effective length? How big is the end effect? (The effect is about twice as big compared to the previous tube because there are two open ends.)

5. To store the fundamental frequency in the Sine Wave Generator's memory, press and *hold* the Store/Exit key until the display blinks. Press the up arrow key to increment the frequency up to the second harmonic. Move the tube away and back again to convince yourself that it is at resonance. Repeat for the third harmonic. Draw a companion sketch of the waveform diagrams on page 24 showing the *third* harmonic (remember that L is constant).

6. Return the frequency to the fundamental, and then replace the open tube with the closed tube. Is it still at resonance? Using the coarse frequency knob, decrease the frequency until you find the fundamental resonance of the closed tube.

7. Calculate the ratio of the open-tube frequency to the closed-tube frequency. What should this ratio be? Why.

8. Press and *hold* the Store/Exit key to store the fundamental frequency of the closed tube. Press the up arrow key to increment the frequency up to the second harmonic. Do you hear a resonance? Move the tube away to make sure. Is it louder with the tube near? Press the up arrow key again to increment the frequency up to the third harmonic. Can you hear resonance now? Explain why.

Further Investigations

1. Why does a tube open at both ends play all the harmonics, but a tube with one end closed only plays the odd harmonics (1, 3, 5, etc.). What is the relationship between the tube length and the wavelength for the third harmonic of a closed tube?

2. Draw a companion sketch of the waveform diagram in Part I on page 22 (closed tube) showing the third harmonic in a tube of the same length. Remember that you must still have a node at the closed end and an anti-node at the open end. Why is this set of pictures different from what you drew in Part I? In each case, what is forced to stay constant, and what is allowed to change?

3. If twirlable Sound Tubes are available, twirl one around in a circle. As you spin it at different speeds you will hear different notes. How are these notes related? Spin a tube of different length. Which tube plays the lower frequency? How is tube length related to frequency?

Experiment 1:
Teachers' Notes–Standing Waves in Strings

String

Slope = 97900 Hz^2/kg

$$\text{Density} = \mu = \frac{4\left(9.8\ \text{m/s}^2\right)}{\left(97900\ \text{Hz}^2/\text{kg}\right)(1.23\ \text{m})^2} = 2.65 \times 10^{-4}\ \text{kg/m} = 0.265\ \text{g/m}$$

$$\text{Actual Density} = \frac{1.58\ \text{g}}{6.09\ \text{m}} = 0.259\ \text{g/m}$$

% Deviation = 2%

Cord

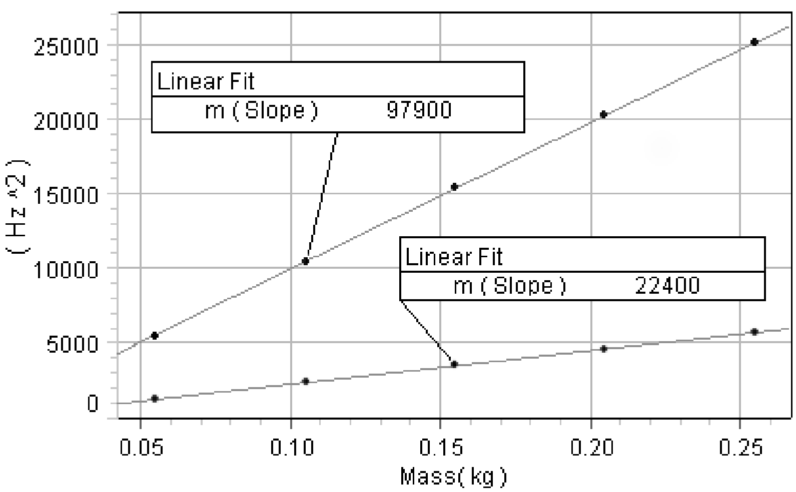
Slope = 22400 Hz^2/kg

$$\text{Density} = \mu = \frac{4\left(9.8\ \text{m/s}^2\right)}{\left(22400\ \text{Hz}^2/\text{kg}\right)(1.23\ \text{m})^2} = 1.16 \times 10^{-3}\ \text{kg/m} = 1.16\ \text{g/m}$$

$$\text{Actual Density} = \frac{2.36\ \text{g}}{2.00\ \text{m}} = 1.18\ \text{g/m}$$

% deviation = -2%

	String		Cord	
m **(kg)**	***f*** **(Hz)**	***f^2*** **(Hz^2)**	***f*** **(Hz)**	***f^2*** **(Hz^2)**
0.055	74.1	5491	34.8	1211
0.105	102.1	10424	48.2	2323
0.155	124.1	15401	58.9	3469
0.205	142.2	20221	67.7	4583
0.255	158.3	25059	75.4	5685



Elastic Cord

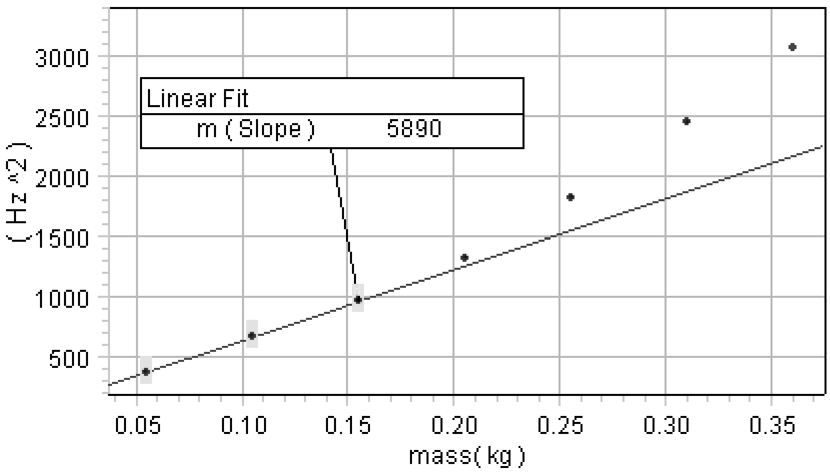
Minimum Slope = 5890 Hz^2/kg

$$\text{Density} = \mu = \frac{4\left(9.8\ \text{m/s}^2\right)}{\left(5890\ \text{Hz}^2/\text{kg}\right)(1.23\ \text{m})^2} = 4.4 \times 10^{-3}\ \text{kg/m} = 4.4\ \text{g/m}$$

$$\text{Actual Density (unstretched)} = \frac{5.58\ \text{g}}{1.3\ \text{m}} = 4.3\ \text{g/m}$$

% Deviation = 2%

	String	
***m* (kg)**	***f* (Hz)**	**f^2 (Hz^2)**
0.055	19.3	372
0.105	25.7	660
0.155	31.0	961
0.205	36.3	1318
0.255	42.7	1823
0.310	49.4	2440
0.360	55.4	3069

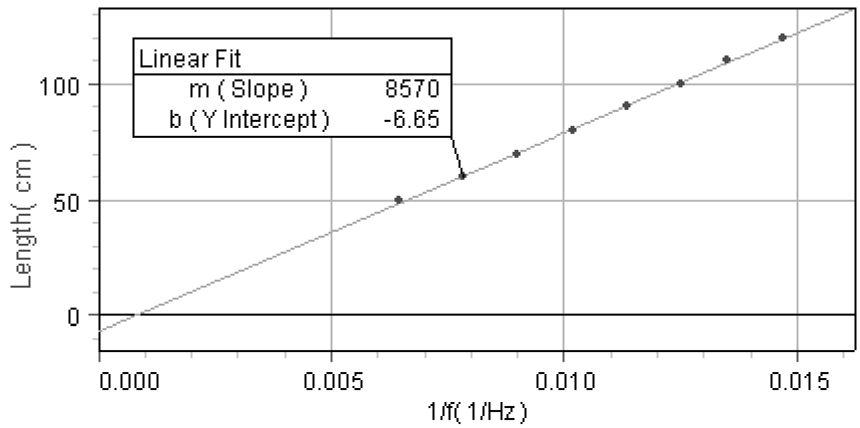


Experiment 2:
Teachers' Notes–Resonance Tubes

If you have twirlable Sound Tubes (SE-8692), trim them to slightly different lengths so they play different notes.

Part I

L (cm)	*f* (Hz)	1/*f* (1/Hz)
120	68	0.015
110	74	0.014
100	80	0.013
90	88	0.011
80	98	0.010
70	111	0.0090
60	128	0.0078
50	155	0.0065



Slope = 8570 cm/s = 85.7 m/s

v = 4 (85.7 m/s) = 343 m/s

v = 331 m/s + (0.6)(25 °C) = 346 m/s. (The scale factor in this formula should have units of K^{-1}. That detail has been omitted for simplicity.)

% Deviation = -1%

Tube Diameter = 14.5 cm

End Effect = 0.3(14.5) = 4.4 cm, as compared to the y-intercept, which is 6.7 cm. Still, this shows the concept that the wave extends outside the end of the tube by several centimeters. Ask students to consider the uncertainty of the best-fit line's y-intercept.

Further investigations:

f = 230 Hz

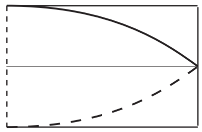
Position of first node = 104 cm

Position of second node = 28 cm

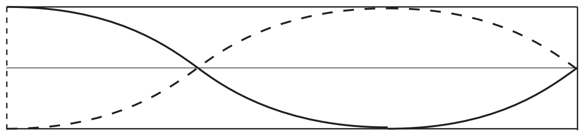
λ = 2 (104 cm - 28 cm) = 152 cm

v = λf = (1.52 m)(230 Hz) =350 m/s

% Deviation = 1%



1st Harmonic



3rd Harmonic

Part II

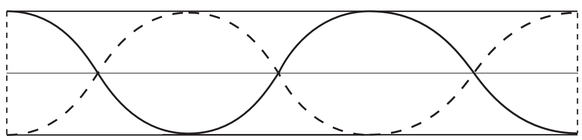
f_1 = 122 Hz (fundamental)

λ = (346 m/s)/(122 Hz) = 2.84 m

L = 1/2 λ = 1.42 m (effective length)

Actual Tube Length = 1.31 m

End effect (per end) = (1.42 m-1.31 m)/2 = 5.5 cm, which is between the values from Part I.



3rd Harmonic

Safety

Read the instructions before using this product. Students should be supervised by their instructors. When using this product, follow the instructions in this manual and all local safety guidelines that apply to you.

Technical Support

For assistance with any PASCO product, contact PASCO at:

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Fax: (916) 786-3292

Web: www.pasco.com

Email: techsupp@pasco.com

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Limited Warranty

For a description of the product warranty, see the PASCO catalog.

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