The Video Encyclopedia of Physics Demonstrations™
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CHAPTER 25

STANDING SOUND WAVES
The detailed structure of resonance and standing waves in an acoustical closed end tube is investigated in this demonstration. A closed tube is excited at its open end by a sinusoidal wave from a small loudspeaker. As a plunger is moved away from the open end, resonances occur whenever the length of the tube (ignoring the end correction) is an odd number of quarter wavelengths long. The sound signal displayed on the oscilloscope is observed using a small microphone immediately in front of the plunger. A maximum response of the microphone indicates that there is a pressure antinode (or a velocity node) at the closed end and a pressure node (or velocity antinode) at the open end, so the proper arrangement of standing wave loops just fits into the closed tube. The sound that is heard on the video is picked up by an external microphone. The microphone inside the tube is hooked only to the oscilloscope. The frequency is increased in the second segment of the demonstration, so that the distance between the pressure antinodes can be compared with those for the lower frequency. In the final segment of this demonstration the microphone is moved along the axis of the tube when the plunger is at a resonant position, as shown in Figure 1, illustrating the structure of the standing waves.

Figure 1
This glass tube contains a movable piston. We'll drive this small speaker at the end of the tube at 1500 hertz and show resonance at different tube lengths by moving the piston.

When the sound intensity is greatest, the tube is in resonance.

If we mark the positions of the piston which give us resonances, we see that they are regularly spaced.

We'll now increase the driving frequency and repeat the action.

What will happen to the spacing of the positions that produce resonance?

The new spacing is shorter.

This small microphone will now be moved inside the tube while the tube is in resonance. The output of the microphone will be displayed on this oscilloscope.

**Equipment**

1. Glass tube with a piston through which a small diameter tube containing the necessary wires and on which a small microphone is mounted on its end that passes through the center of the piston's head and having the capacity to slide through the moveable piston when it is stationary.
2. Amplifier.
3. Oscilloscope.
4. A small speaker, approximately the same size as the tube's diameter, mounted at the end of the tube, thereby creating an enclosed cavity.
5. Audio oscillator.
6. Meter stick.
7. Appropriate electrical leads.
Three closed tubes are excited by blowing air across the opening at one end of the tube, as shown in Figure 1. The fundamental, or first harmonic, mode of each tube consists of one-half loop of a standing wave, with a pressure node, or velocity antinode at the open end and a pressure antinode, or velocity node, at the closed end. Thus the wavelength is longer for the longer tubes and the longer the tube the lower the frequency, as can be easily heard in the video. In the video the loudest tone produced for each tube is the third harmonic, up one octave and a fifth from the fundamental, for which the tube is \( \frac{3}{4} \) of one wavelength long. Both the fundamental and the third harmonic can be heard on the video.

This glass tube will resonate when air is blown across the opening.

If we repeat this action with a longer tube, how will the frequency change?

The frequency of the sound is now lower.

Here is a longer tube with a still lower frequency.

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**Equipment**

1. Three glass tubes with equal diameters, but varying lengths; each with a cork in one end and the opposite end open.
2. Supply of compressed air running through a hose with a broad flat nozzle.
**Demo 11-03  Kundt’s Tube**

A Kundt’s tube uses light powder such as cork dust to render the motion of the air in a standing wave “visible,” as illustrated in Figure 1.† The cork dust becomes agitated where the air is in motion, and is quiescent at the positions in the standing wave where the air is quiescent. The striations seen in the response of the cork dust are due to small circulating cells of air.‡


We'll use this long glass tube and some cork dust to demonstrate standing sound waves in a column of air.

The standing waves will be produced by driving the air in the tube with the output from this rod.

When a standing wave forms, the motion of the air pushes the cork dust into regularly spaced piles.

**Equipment**

1. Commerically available Kundt's tube.
2. Supply of fine, dry cork dust.
4. A rag.
A tube with one end closed resonates at a frequency approximately one octave lower (a factor of two in frequency) than an open tube of the same length.† When one end of the tube in the video is closed the resonant frequency is 256 Hz, as can be clearly heard on the video. In the final segment of this video the cap is removed from the closed end of the tube, so it becomes an open tube that resonates at 512 Hz, as shown in Figure 1.
We'll use this metal tube to show the difference in resonant frequency of a tube with open closed ends.

This 256-hertz tuning fork will excite the closed end tube.

But will not excite the tube when the end is open.

When both ends of the tube are open, this 512-hertz tuning fork will strongly excite a standing wave in the tube.

When the opposite ends close the 512-hertz fork no longer excites the tubes strongly.

**Equipment**

1. A length of tubing, with one end for quick and easy opening and airtight closing.
2. 256-Hz tuning fork.
3. 512-Hz tuning fork.
4. Rubber mallet.
5. Support system for resonance tube.
Three organ pipes, shown in Figure 1, are each blown with a cap on the end and without the cap.† Without the cap the frequency is higher by about a factor of two, or one octave. Due to the end correction, the frequency ratio is actually slightly less than an octave.

These small organ pipes produce tones of definite frequencies when they are blown.

Each pipe has an end piece which may be removed to show the effect on frequency.

Here is the first pipe, first with the end piece,
then without.

Here is the second pipe, first with the end piece,
then without.

Here is the third pipe, first with the end piece,
then without.

**Equipment**

Three organ pipes with differing lengths and widths—each with a removable end plug.
Slide Whistle

A slide whistle, shown in Figure 1, is a closed tube resonator that produces its sound using edge tones.† The closed end of the whistle can be moved in and out to raise and lower the frequency of the resonance, as can be readily heard in the video.

This wood whistle produces a sound with a certain frequency when blown.

If we shorten the air column inside the whistle by moving this end stop, how will the frequency produced compare with the original frequency?

The new frequency is higher,

and continues to increase as the length of the air column is shortened.

**Equipment**

Commercially available wooden slide whistle (organ pipe).
Singing pipes are resonant acoustical open tubes that achieve their sound from the noise generated by convection currents. The first two metal tubes are excited directly by the flame from a torch.† In the third tube, a glass tube, a flame is used to heat metal gauze in the tube.‡ When the flame is removed, as in Figure 1, the convection currents created in the tube by the air heated by the hot gauze create a noise spectrum that leads to a sound resonance in the tube, as can be readily heard. When the tube is tipped to a horizontal orientation, no convection currents can flow so the tube does not sing.

‡ Sutton, *Demonstration Experiments in Physics*, Demonstrations S-62 and S-64.
These pipes will produce loud musical sounds when a gas burner is placed inside them at just the right point.

This tube produces sound at its resonant frequency.

This pipe is longer than the first. It produces a sound with a lower frequency.

This glass tube has a stainless steel screen inside which we heat with a burner until it is red-hot. Hot air rising from the screen causes the tube to produce a musical tone.

If we turn the tube on its side, it no longer produces sound. Returning the tube to a vertical position restores the sound.

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**Equipment**

1. Two tin pipes of equal diameter, but differing lengths and open ends.
2. Support system for pipes.
3. Meker burner.
5. Source of flame.
6. Length of glass tube with a piece of stainless steel wire mesh embedded in the glass at a position approximately one-fourth its length.
When a tuning fork is sounded and held in the air, the sound is weak due to the poor acoustic coupling between the tuning fork and the air. If the tuning fork is struck and acoustically coupled to a box of the proper size, as in Figure 1, the box functions as a resonator at the frequency of the tuning fork, the sound of the tuning fork is much louder, as can be heard on the video.† When the tuning fork is placed on a box of a different resonant frequency, the sound does not become as loud, as demonstrated in the video.

When this tuning fork is struck, the sound it produces is relatively faint.

If we place it in a box designed to resonate at the same frequency as the fork, the sound is much louder.

When we strike the fork and place it in this larger box, the sound is not as loud.

But the sound from this lower frequency tuning fork does increase strongly when placed in the larger box.

**Equipment**

1. Two tuning forks of different frequencies.
2. Two resonance boxes of appropriate size for the tuning forks.
3. Rubber mallet.
4. Foam rubber pads for the resonance boxes to minimize the energy losses.
A Helmholtz resonator is a hollow sphere with a large neck and a smaller nipple that can be inserted into the ear to observe the resonant behavior of the resonator.† When a tuning fork at the frequency of the resonator is held near the resonator, as shown in Figure 1, the sound of the tuning fork becomes louder. Two combinations of tuning forks and Helmholtz resonators are shown on the video.

These brass spheres will be used to demonstrate sound resonance in an open cavity.

When we strike a tuning fork with a frequency of 256 hertz and hold it up to the first resonator, a strong sound is heard.

Putting the same fork up to the second resonator does not produce as loud a sound.

This tuning fork, with a frequency of 512 hertz, produces a strong resonance in the second sphere,

but has less effect on the first sphere.

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**Equipment**

1. Two Helmholtz resonators of differing sizes (256 & 512 Hz).
2. Two cylindrical supports for the resonators.
3. 256-Hz tuning fork.
4. 512-Hz tuning fork.
5. Rubber mallet.
CHAPTER 26

GAS PRESSURE
In a barometer the outside air pressure pushes a column of mercury up a small tube to a height of about 76 cm.† If the external air pressure is largely removed by a vacuum pump, as shown in Figure 1, the column of mercury will fall to only a few centimeters in height.‡ In the video the “barometric pressure” is reduced to the pressure of the vacuum pump and then allowed to increase to normal atmospheric pressure.

† Sutton, Demonstration Experiments in Physics, Demonstration M-324, Barometer Tube.
‡ Freier and Anderson, A Demonstration Handbook for Physics, Demonstration Fd-4, Low Barometric Pressure.
Here is a simple mercury barometer inside a large glass tube.

If we evacuate the air from the outer glass tube, the mercury level in the barometer falls as less and less air presses on the surface of the mercury.

When most of the air is gone, the height of the mercury column has fallen nearly to zero.

If we allow air back into the outer tube, the mercury column rises to its former height.

This animation shows the pressure exerted by the air on the surface of the mercury.

When the pressure pushing the mercury up the tube is removed by removing the air, the mercury column falls.

**Equipment**

1. Simple mercury barometer.
2. Barometer bell jar.
3. Pump plate with support system for the glassware.
4. Vacuum tubing.
5. Vacuum pump.
An “aneroid barometer” measures the atmospheric pressure by comparing the pressure inside and outside a sealed compartment.† The motion of a diaphragm as the outside pressure changes provides the barometer indication. In the video, an aneroid barometer is used to measure pressure changes as the demonstrator blows into or sucks on the chamber surrounding the membrane, creating a pressure change that is measured by the aneroid barometer, as shown in Figure 1.

† Freier and Anderson, A Demonstration Handbook for Physics, Demonstration Ff-2, Aneroid Barometer.
This device, known as an aneroid barometer, is used to measure atmospheric pressure. This flexible metal diaphragm encloses a small amount of air. When the external air pressure increases, the diaphragm is compressed, turning this pointer which indicates the pressure.

This aneroid barometer is sealed inside an airtight chamber. If we blow air into the chamber, the pressure is increased and the pointer moves.

Sucking air out of the chamber lowers the pressure inside.

The flexible diaphragm is pulled outward, and the pointer moves the other way.

**Equipment**

1. Commercially available demonstration aneroid barometer with vacuum chamber.
2. Rubber tubing.
Magdeburg hemispheres, named after the city in which they were first used, illustrate the pressure of the atmospheric air. Two steel hemispheres are positioned together, and the air pumped out from inside the sphere. The spheres are then held together by a force arising from the air pressure, which is equal to the cross-sectional area of the spheres multiplied by the air pressure. In the video this force is used to hold up a group of weights, as shown in Figure 1.

We'll use these two small hemispheres to demonstrate the force due to air pressure.

If the hemispheres are placed together with air inside, pressure is the same inside and outside and the hemispheres are easily separated.

But if we remove the air from the inside with a vacuum pump, the air pressure on the outside is no longer balanced by pressure on the inside.

The hemispheres will support a large weight without separating.

When air is allowed back in, the hemispheres fall apart.

This animation shows the forces due to air molecules striking the inner and outer surfaces. Normally they balance, but when the air is removed the force on the inner walls vanishes.

The unbalanced force on the outer walls must be overcome to separate the hemispheres.

**Equipment**

1. Magdeburg hemispheres.
2. Vacuum grease.
3. Vacuum tubing.
4. Vacuum pump.
5. Tall ring stand.
6. Clamp and bar.
7. S hooks.
8. Weight hanger.
10. Foam rubber pad to protect tabletop.
This demonstration illustrates the force of cohesion between two glass plates.† Two glass plates are carefully cleaned and pressed together, as shown in Figure 1. The plates hang tightly together, due to both the cohesion between the glass surfaces and the external air pressure. They can be separated by sliding them apart sidewise.

These thick glass plates have surfaces that are microscopically flat.

When they are pushed together, the air between the two faces is squeezed out.

The atmospheric pressure outside the plates now holds them together.

**Equipment**

Adhesion plates.
This demonstration uses air pressure to crush a can.† When the air is pumped from the can, the can collapses, as shown in *Figure 1*. The difference in pressure on the inner and outer surfaces of the can provides the forces that crush the can.

We'll use atmospheric pressure to crush this steel can.

A vacuum pump hooked to the can begins removing the air inside.

As the internal air pressure drops, the external air pressure crushes the can.

This animation shows the forces due to air pressure on the inner and outer surfaces of the can.

As the air is removed, the internal pressure drops while the external pressure stays the same. When the difference between the two is great enough, the can is crushed.

**Equipment**

1. Gallon can
2. One-hole rubber stopper of appropriate size.
3. Vacuum tubing.
4. Vacuum pump.
5. Piece of metal tubing matching the inside diameters of number 2 and number 4.
The “vacuum bazooka” is a device that uses atmospheric pressure to propel a ball. The air is pumped out of a tube, the ends of which have been sealed by loose sheets of material, as shown in Figure 1, and a ball placed in one end of the tube adjacent to the seal. When that seal is knocked off with a mallet, the force of the atmospheric air pressure, and the lack of air pressure on the other side of the ball, accelerate the ball. The muzzle end seal is blown off by the ball as it leaves the tube at high speed.
We'll use the power of atmospheric pressure to launch a rubber ball at high speed.

The rubber ball is put inside this long tube, and both ends of the tube are sealed with metal plates.

A vacuum pump attached to the tube then removes the air from the tube.

When the tube is completely evacuated, the metal plate nearest the rubber ball is knocked off.

The rush of air into the tube blows the rubber ball out the other end of the tube at high speed.

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**Equipment**

1. Long length of metal pipe with square cut ends and equipped with a vacuum port for vacuum tubing.
2. Support system for pipe.
3. Dead weight to hold bazooka down.
4. Flat end cover plates with bonded rubber sheets for sealing; with the front plate having a safety rope.
5. Supply of vacuum grease.
6. Vacuum tubing.
7. Vacuum pump.
8. Firm rubber ball whose diameter is essentially identical to the inside diameter of the pipe—best to be about 1/32" less than the pipe.
9. Target for bazooka.
10. Assistant.
In this very dramatic demonstration of air pressure a 55-gallon barrel is crushed by atmospheric pressure.† Water is boiled in the barrel to fill it with steam and water vapor. The barrel is then sealed and cooled with ice. When the steam condenses, its volume shrinks by a factor of about 1000, reducing the pressure within the barrel dramatically. The external air pressure then is sufficient to crush the barrel with a dramatic crack, as shown in Figure 1.

† Sutton, Demonstration Experiments in Physics, Demonstration M-326, Collapse of Tin Can.
We'll use atmospheric pressure to crush this sturdy steel barrel.

To accomplish this feat we must remove the air from the inside of the barrel so that it no longer balances the pressure from the external air.

To remove the air, we'll put a small amount of water in the bottom of the barrel.

Gas burners heat the water to boiling, and steam from the boiling water gradually drives the air out of the barrel.

When all the air is replaced by steam, the barrel is capped tightly.

Now we'll cool the barrel by loading ice onto the top.

As the steam cools it condenses to liquid water, which falls to the bottom of the barrel.

The steam pressure inside no longer balances the tremendous force due to external air pressure, and the barrel is crushed.

**Equipment**

1. 55-gallon barrel.
2. Four gallon cans to elevate barrel above burners.
3. Four Meker burners and sufficient tubing.
5. Source of flame.
7. Gloves
8. Plugs for barrel openings.
10. Supply of crushed ice.
**Demo 11-17**  
**Air Pressure Lift**

This video demonstrates pressure distribution through a confined fluid, Pascal’s Law. A subject stands on a board that has been placed on top of a hot water bottle. Blowing air from the experimenter’s mouth into a tube connected to the hot water bottles provides sufficient pressure and upward force to lift the subject, as seen in *Figure 1*.

*Figure 1*
We'll place these hot water bottles underneath a board, and have a person stand on top of the board.

If we want to lift this person by running pressurized air into the bottles, approximately how many atmospheres of pressure would it take to get the person off the ground?

It can be done with lung power just by blowing into the tube attached to the bottles.

Only a fraction of one atmosphere is required to provide enough total force to lift the person.

**Equipment**

1. Two hot water bottles.
2. Board large enough to cover both bottles when lying side by side.
3. Bottle plugs fitted for rubber tubing.
4. Rubber tubing.
5. Glass or metal “T” mouthpiece.
**Demo 11-18**  

**Inertia Shingles**

A long thin board is placed on a table with about half of the board extending over the edge of the table. The section of the board on the table is then covered with a sheet of newspaper. The end of the board is then struck a sharp blow, as in *Figure 1*, breaking the board. The air pressure on the newspaper creates a strong force on the board, causing it to break.

*Figure 1*
We'll use the pressure of the atmosphere to help break this wood shingle. The shingle is placed at the edge of the table, and a piece of paper is placed over it.

When the shingle is struck a rapid blow with a hand it breaks, but the paper barely moves.

**Equipment**

1. Wooden shingles or shim stock.
2. Flat pieces of paper.
3. Solid table edge with sufficient clearance below.
In this demonstration the atmospheric pressure of air is used to lift a chair. A thin sheet of rubber, attached in the center to a handle, is placed tightly on the seat of a chair, as seen in Figure 1. When the handle is grasped firmly and lifted, the atmospheric pressure of the air keeps the rubber sheet in contact with the chair, allowing the chair to be lifted.
This thin rubber sheet will be used to demonstrate the large forces produced by air pressure.

When the sheet is placed on top of this stool, the air between the sheet and the stool is driven out.

The air pressure on the top of the sheet holds the sheet to the stool with enough force to allow the stool to be lifted off the ground with the sheet.

**Equipment**

1. Stool or chair with smooth seats.
2. Flexible thin rubber sheet.
3. Weight hanger carefully squeezed through small center hole of rubber sheet.
4. Short metal bar for easily gripping the weight hanger hook.