

The
Video
Encyclopedia
of
Physics
Demonstrations™

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C H A P T E R 2 0

R E S O N A N C E

A bowling ball, hanging from a long rope, is struck by a mallet in a random series of blows, resulting in small, random motions of the bowling ball pendulum. When it is struck at the normal frequency of the pendulum, it attains sinusoidal motion of significant amplitude, as shown in *Figure 1*.



Figure 1

This bowling ball pendulum will be used to demonstrate resonance.

The pendulum swings with a natural frequency of about one swing every two seconds.

We'll drive it by striking it with a rubber mallet.

First we'll drive the pendulum by striking it repeatedly at short intervals. Even after many blows, the pendulum isn't moving very far.

But if we change the striking frequency to the natural frequency of the pendulum, the amplitude increases with each blow of the mallet.

Equipment

1. Bowling ball pendulum.
2. Suspension system as described earlier.
3. Rubber mallet.

A weight mounted securely on a hanging rod forms a physical pendulum that is coupled to a rocker bar that rotates at the frequency of the physical pendulum. Attached to the rocker bar are three independent simple pendula. When the weight is adjusted so that the period of the physical pendulum is equal to that of one of the simple pendula attached to the rocker bar, oscillation of the physical pendulum will drive the simple pendulum of the same frequency, as shown in *Figure 1*.



Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Sd-1, Resonance Pendula.

This physical pendulum drives a rocker bar, which in turn drives three simple pendula hanging from the bar.

The driving frequency can be changed by moving a weight on the physical pendulum.

The weight is first adjusted so that the driving frequency is equal to the natural frequency of the longest pendulum.

If the three pendula are initially stationary, only the longest pendulum responds strongly.

The weight is now adjusted so that the driving frequency matches the frequency of the middle pendulum.

Notice the strong response of the middle pendulum, and the different phase lags between the driver pendulum and each of the three simple pendula.

Equipment

1. Massive physical pendulum firmly fixed to a rocker bar with a bob whose position can quickly and easily change with a thumb screw.
2. Support system.
3. Three pendula with bifilar suspension of differing lengths, each independently supported from the rocker bar.

A mass on the end of a spring is driven by a mechanical oscillator, as shown in *Figure 1*, at frequencies below, at, and above the resonant frequency of the mass on the spring.[†] The resulting amplitude of vibration of the mass on the spring and the phase of the oscillation of the mass relative to that of the driving force can be observed on the video.[‡]



Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration S-13, Forced Vibrations and Resonance.

[‡] Sutton, *Demonstration Experiments in Physics*, Demonstration S-14, Forced Vibrations and Resonance—Phase Relations.

This spring and weight hang from a driver whose frequency can be adjusted with this control.

We'll increase the driving frequency slowly and watch the effect on the motion of the weight.

At low frequencies, the mass moves very little.

As the frequency increases, the amplitude of oscillation increases until the mass strikes the table. The weight is now lagging behind the driver, which is moving at the resonant frequency of the spring and weight.

When the frequency is increased further, the amplitude of oscillation decreases.

Equipment

1. Spring and weight.
2. Variable speed, motor-driven suspension point and support assembly.
3. Motor speed control.

A pendulum model of a child swinging is formed from a mass hanging on a string that passes over a pulley and is attached to a fixed point. If the pendulum is started into motion with a small amplitude, it can be “pumped up” to a large amplitude in much the same way that a child pumps a swing.[†] When the swing is at the low point of its oscillation, the support rope is gently pulled, decreasing the length of the pendulum and raising the center of mass of the weight representing the swinging child. This raising of the center of mass is what a child does when “pumping” the swing. When the radius of the pendulum gets shorter, conservation of angular momentum results in an increase in the speed of the swinging mass, adding mechanical energy to the swing and thus allowing it to rise higher.

A more complete and exacting description of pumping a swing suggests parametric instability as the principal concept.[‡]



Figure 1

[†] Little Thinkers: A Child's Swing, *The Physics Teacher* 4, 307, 374-375 (1966).

Peter L. Tea, Jr. and Harold Falk, Pumping on a Swing, *Am. J. Phys.* 36, 1165-1166 (1968).

Stephen M. Curry, How children swing, *Am. J. Phys.* 44, 924-926 (1976).

[‡] William B. Case and Mark A. Swanson, The pumping of a swing from the seated position, *Am. J. Phys.* 58, 463-467 (1990).

These children know how to pump a swing so that the swing goes higher and higher with each pass. But how is it actually done?

This demonstration will use a pendulum on a string in place of a swing to show how it is achieved.

The string of the pendulum passes over a pulley so that the weight can be raised or lowered slightly. If the pendulum is set swinging with a small amplitude, we can pump it up by pulling up on the string each time the weight gets to the bottom and releasing it as it reaches the top.

We do the same on a swing by raising our legs and pulling back on the ropes as we pass the bottom, then letting go at the top of each swing.

Equipment

1. Tall ring stand.
2. Clamp and cross bar.
3. Clamp and bearing pulley.
4. Weight.
5. Long piece of string.

A reed tachometer can be used to determine the frequency of a vibrating object. A series of reeds of varying length vibrate as a small unbalanced gyroscope to which the reeds are attached slows down, passing through the resonant frequency of each reed in turn. One vibration is shown in *Figure 1*.

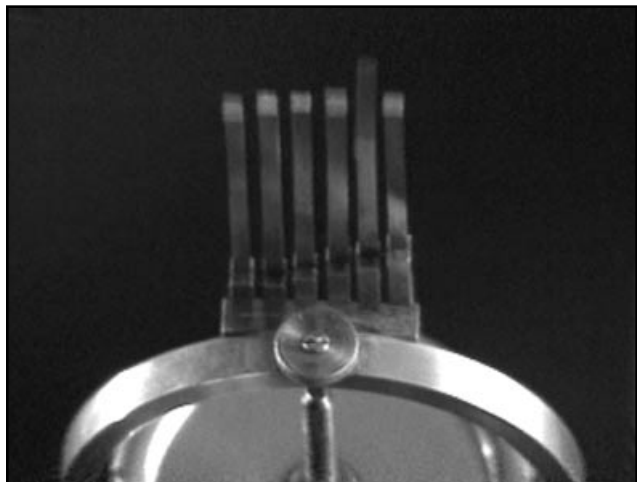


Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration S-15, Resonance Top and Vibration Tachometer.

Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Mx-13, Resonance Reeds.

This reed tachometer consists of a group of metal reeds of varying lengths attached to a gyroscope. The reeds have different frequencies of oscillation. The gyroscope wheel is unbalanced so that it vibrates slightly when it spins.

We'll spin the gyroscope and watch what happens to the reeds as the gyroscope slows down and the vibration frequency changes from high to low.

Equipment

1. Reed tachometer.
2. Motor with rubber covered start-up disc.
3. Clamps.

A glass beaker is caused to vibrate by exposing it to the sound wave produced by a high-power loudspeaker. If the frequency of the oscillator is set to exactly the resonant frequency of the beaker, the oscillations of the beaker can easily exceed the elastic limit of the glass, and the beaker will shatter,[†] as shown in *Figure 1*. This demonstration has been compared with the supposed shattering of a wineglass by a singer, which is totally without basis in fact.[‡]



Figure 1

[†] Thomas D. Rossing, Wine Glasses, Bell Modes, and Lord Rayleigh, *The Physics Teacher* 28, 582-585 (1990). Haym Kruglak, Robert Hiltbrand and Don Kangas, Shattering Glass with Sound Simplified, *The Physics Teacher* 28, 418 (1990).

[‡] Haym Kruglak and Rene Pittet, The Caruso Legend Lives on, *The Physics Teacher* 17, 49 (1979).

We will demonstrate resonance by breaking a glass beaker with a sound wave.

This beaker has a natural oscillation which can be produced by gently tapping its brim. We create a resonance by exposing the beaker to a sound wave of the same frequency.

For this demonstration we use a stable oscillator,

a power amplifier,

and a horn driver which can handle a large amount of power.

The beaker is positioned on a foam rubber pedestal in front of the hole from which the sound emerges. The sound wave emitted by the vibrating beaker is picked up by the microphone to the left of the beaker and displayed on the oscilloscope, the oscilloscope is triggered by the signal from the oscillator, but displays the signal emitted by the beaker, so that both the amplitude increase and the phase shift can be observed as the frequency is tuned through resonance.

The frequency of the oscillator has now been set to the natural frequency of the beaker.

Using a stroboscope, the oscillations of the brim of the beaker can be viewed from above.

Returning to a front view of the beaker, we now increase the amplitude of the sound wave until the oscillation of the beaker exceeds its elastic limit.

Equipment

1. Highly stable audio oscillator.
2. Power amplifier.
3. Horn driver.
4. Support system for number 3 and a microphone.
5. Foam rubber pad.
6. Oscilloscope.
7. Strobe light.
8. Safety shield.

Two identical physical pendula are coupled by a spring.[†] When one of the pendula is started into motion, the motion will couple through the spring, and the energy will transfer back and forth from one pendulum to the other, as shown in *Figure 1*. If the coupling is increased, by using a stiffer coupling spring, the transfer of energy will occur more rapidly. If the two pendula do not have the same natural frequency, the energy will not transfer completely from one pendulum to the other.



Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Mx-10, Adjustable Coupled Pendulum.

This pair of physical pendula have the same period. If we connect the pendula together with a light spring and set one in motion, the second pendulum also begins to move.

Soon both pendula have nearly equal motions.

Now the second pendulum has all the energy and the first pendulum has nearly stopped.

The energy has now gone full cycle, with the first pendulum in full motion and the second at rest.

If we connect the two pendula with a stiffer spring, the energy is exchanged much more quickly.

If we change the period of one of the pendula by moving a weight, the energy no longer passes completely from one pendulum to the other.

Equipment

1. Two physical pendula whose identical bobs can have their position adjusted and which are supported from low friction-bearing systems.
2. Supporting system.
3. Hooks on both pendula near their midpoints.
4. Several springs with varying spring constants.

A Wilberforce pendulum consists of a mass hanging from a spiral spring, shown in *Figure 1*, such that two modes of oscillation exist: longitudinal, as in the standard case of a mass on a spring, and torsional, or twisting motion of the spring.[†] When the frequencies of these two oscillations are the same, the motion will couple back and forth between the two modes. This is accomplished by adjusting the moment of inertia of the mass hanging on the spring by moving the nuts in and out on the threaded rod shown in *Figure 1*. In the video the motion is observed for one complete cycle. Further theory of the Wilberforce pendulum is discussed, a procedure is set forth by which the normal modes can be set up, and a number of references are given in a recent paper.[‡]

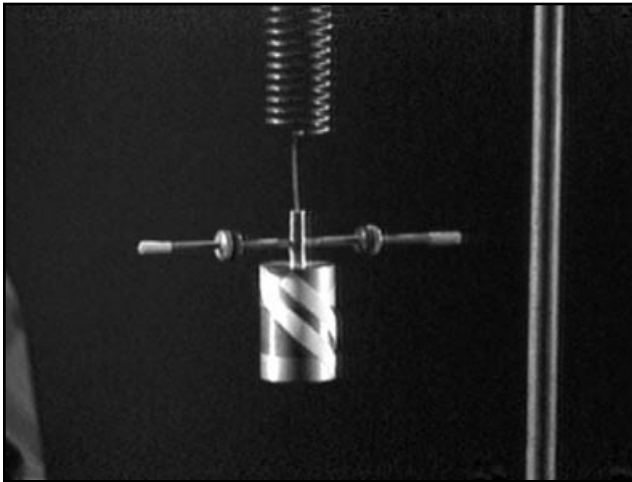


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration S-18, Transfer of Energy from Translation to Rotation.

Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Mx-11, Wilburforce (SIC) Pendulum.

[‡] Richard E. Berg and Todd S. Marshall, Wilberforce pendulum oscillations and normal modes, *Am J. Phys.* 59, 32-38 (1991).

Here is a device called a Wilberforce pendulum. It can oscillate in two ways; vertically, and back and forth in torsional oscillation.

After the pendulum is made to oscillate vertically, energy begins to transfer into torsional oscillation and the pendulum begins to twist.

After a while most of the energy of the pendulum is in torsional oscillations—the pendulum is barely moving in the vertical direction.

Then energy begins to transfer back into vertical oscillations.

Eventually nearly all the energy is in the vertical oscillations and the cycle begins again.

Equipment

1. Wilberforce pendulum.
2. Support system.

C H A P T E R 2 1

M E C H A N I C A L W A V E S

Pulses are set up in a stretched rope and allowed to reflect off the fixed end of the rope back to the end where they started.[†] The initial pulse and its reflection can be observed in the video, as illustrated in *Figure 1*. The sequence is repeated in slow motion.

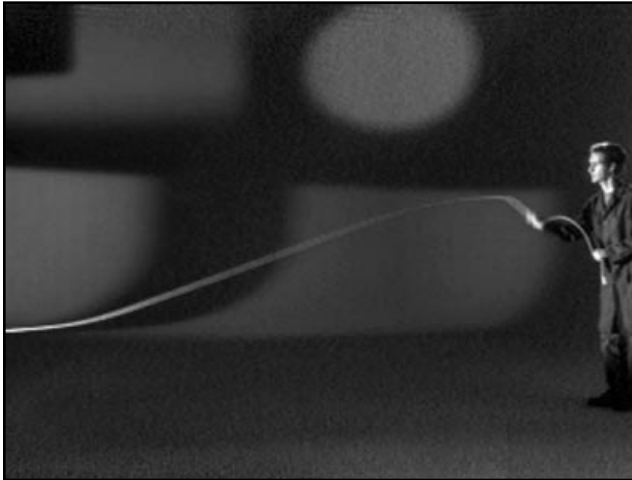


Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Sa-3, Wave Pulse on a Rope.

A long rope attached to the wall can be used to demonstrate wave propagation.

If a sharp pulse is put on the end of the rope, a wave travels down the rope and reflects at the wall.

Let's watch that in slow motion.

Equipment

1. Long rope.
2. Fixed point on distant wall to attach rope.

Demo 09-10

Pulse on Moving Chain

A chain is driven such that it rotates rapidly around a motor at one end and a pulley at the other end. If a pulse is produced on the moving chain by striking it with a hard object, the pulse will move along the chain. However, if the chain is moving at approximately the wave speed of the pulse with respect to the chain, the pulse, as seen in *Figure 1*, will appear to be motionless or to move very slowly.[†]

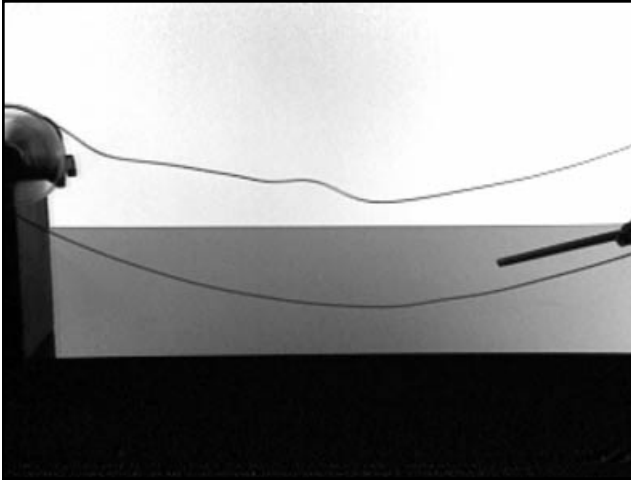


Figure 1

[†] Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Sa-5, Standing Pulse.

When we send a wave pulse along this stationary chain, it travels rapidly down the chain.

We'll start the chain moving in this direction by spinning the support pulleys. When we send a pulse along the moving chain, the pulse appears to move very slowly.

Equipment

1. Motor-driven pulley of sizable diameter with a flat bottom trough.
2. Secondary support pulley with similar characteristics.
3. Long length of flat chain joined back onto itself forming a loop with no twists.
4. Striker bar.
5. Four clamps.
6. Support system.

A transverse pulse is produced in a stretched thin rubber tube, and its speed along the tube noted. If the rubber tube is stretched with a greater tension, the wave will propagate at a greater speed.[†] A split-screen video, shown in *Figure 1*, shows the pulse moving along the tube with three different tensions.

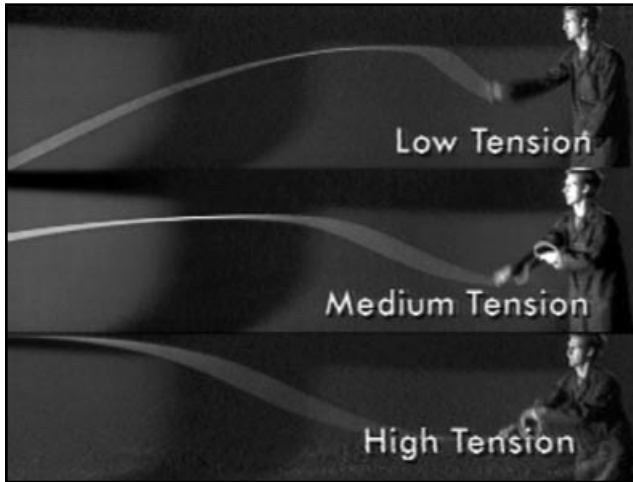


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration S-23, Transverse Waves on Strings.

We can send a wave pulse down this rubber tube by jerking sharply on the free end.

Notice the propagation speed of the wave.

If we increase the tension on the rubber tubing by stretching it, how will the wave speed be affected?

The wave speed increases.

Further increasing the tension will even further increase the speed of the wave.

Equipment

1. Long length of rubber tubing.
2. Fixed point on distant wall to attach rope.

A Shive Wave Machine[†] consists of a horizontal stiff iron wire along which rods have been attached at right angles in the horizontal plane, as shown in *Figure 1*. The video shows wave pulses propagating along the wave machine.



Figure 1

[†] John N. Shive, *Similarities in Wave Behavior* (Bell Telephone Laboratories, third printing, January 1964).

This wave machine is used to demonstrate torsion waves. Long rods are attached to a square metal spine at regular intervals.

If we twist the spine by tipping the first rod, a torsion wave travels down the spine.

Equipment

1. Bell Lab wave machine.
2. Ends of rods should be coated with fluorescent paint.
3. Black lights to highlight the rod tips.

A Shive Wave Machine[†] consists of a stiff iron wire along which rods have been attached at right angles, as shown in *Figure 1*. Two such machines are shown in the video, one of which has shorter transverse rods than the other. Because the moment of inertia of the shorter rods is less than that of the longer rods, the wave propagates at a faster speed in the second machine.

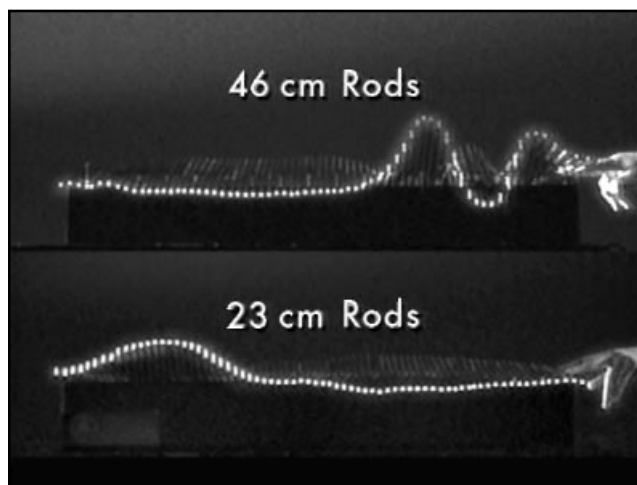


Figure 1

[†] John N. Shive, *Similarities in Wave Behavior* (Bell Telephone Laboratories, third printing, January 1964).

On this wave machine long rods are attached to a square wire spine at regular intervals. If we tip the first rod, a torsion wave travels down the spine.

This wave machine is identical to the first except that the rods are shorter.

A wave travels faster on this machine than on the other one.

Equipment

1. Same set up as previous demonstration.
2. Add a second wave machine, prepared as above, with short rods.

A longitudinal wave model consists of a number of vertical rods, attached by bearings to a support bench and connected by light springs. The rods are free to move in the plane of the rods and their support bar. If the end rod is moved back and forth, a longitudinal wave will be created and propagate down the model as shown in *Figure 1*. Standing waves using this model are shown in Demonstration #24 on this disc.

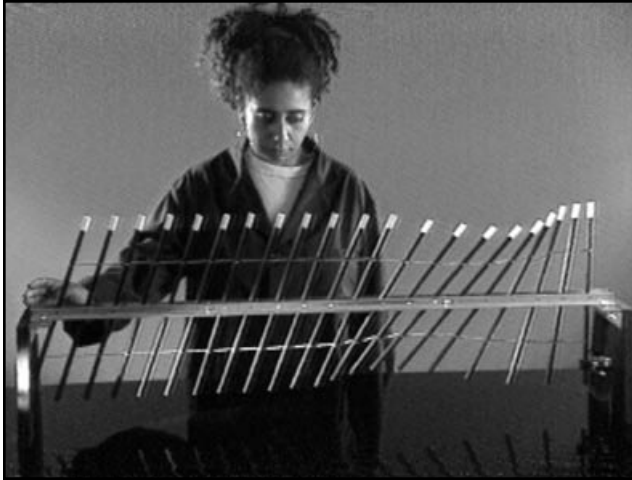


Figure 1

This device is used to demonstrate longitudinal waves, where the displacement of the medium is parallel to the motion of the wave.

When the first rod is pushed sharply, springs between the rods pass the motion along.

Equipment

Commercially available longitudinal wave machine with one end clamp.

Rapidly compressing a section of a suspended Slinky spring and releasing it creates a “compression” which propagates along the spring,[†] as shown in *Figure 1*. Both compressions and rarefactions are illustrated on the video. Standing waves on the Slinky are shown in Demonstration #25 of this disc.

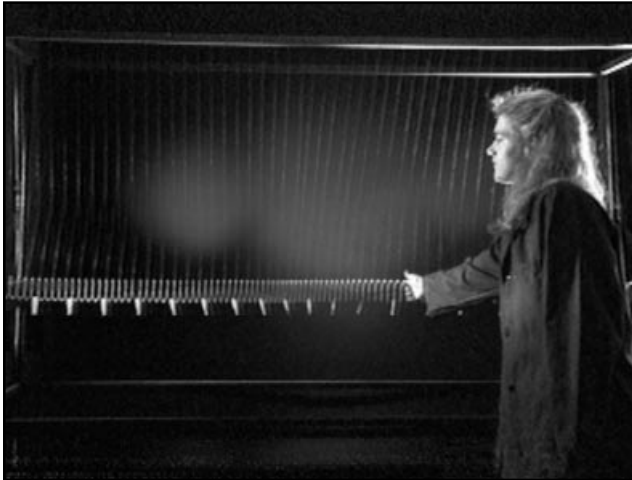


Figure 1

[†] Sutton, *A Demonstration Handbook for Physics*, Demonstration S-39, Longitudinal Waves.
Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Sa-12, Wave Pulses in a “Slinky” Spring.

We'll use this hanging spring to demonstrate transmission of longitudinal waves.

If the end of the spring is compressed rapidly, a compression pulse travels the length of the spring and reflects at the end.

If we pull rapidly on the end of the spring, an expansion pulse travels along the spring.

Equipment

1. Bifilar suspended long metallic Slinky.
2. Supporting framework.
3. Paper flags every fifth coil to enhance visibility.

Wave pulses are superposed on a Shive Wave Machine[†] to illustrate how transverse waves are added. The case of two positive pulses is illustrated on the video, as in *Figure 1*, and the case of opposite pulses, which interfere destructively as they pass by each other on the wave machine.

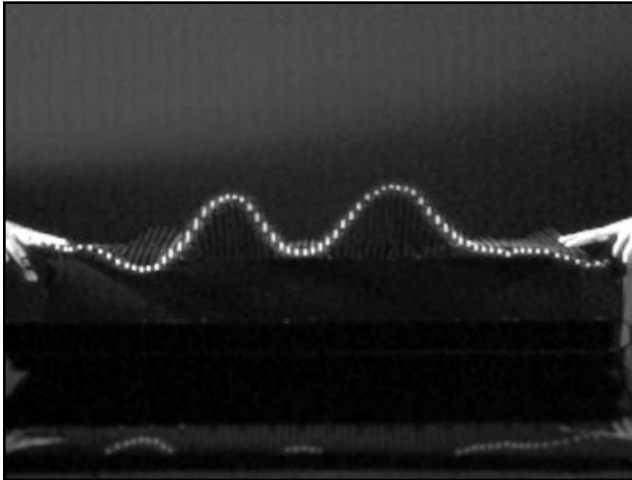


Figure 1

[†] John N. Shive, *Similarities in Wave Behavior* (Bell Telephone Laboratories, third printing, January 1964).

Here is a torsion wave of medium amplitude travelling left to right.

Here is a wave of the same amplitude travelling right to left.

We'll now send these waves in simultaneously to show what happens when they meet. The amplitudes add as the waves pass through each other. Then the waves continue on their way unchanged.

What will happen if the waves have equal but opposite amplitudes?

The waves cancel momentarily, then pass on.

Equipment

Bell Lab wave machine, as previously described.

A pulse is reflected off the end of a Shive Wave Machine.[†] When the reflecting end of the machine is free to move, the reflected pulse is in the same sign (up or down) as the incident pulse, that is, there is no phase change on reflection. When the reflecting end is fixed, a phase inversion occurs; a positive incoming pulse reflects as a negative pulse, as shown in *Figure 1*.

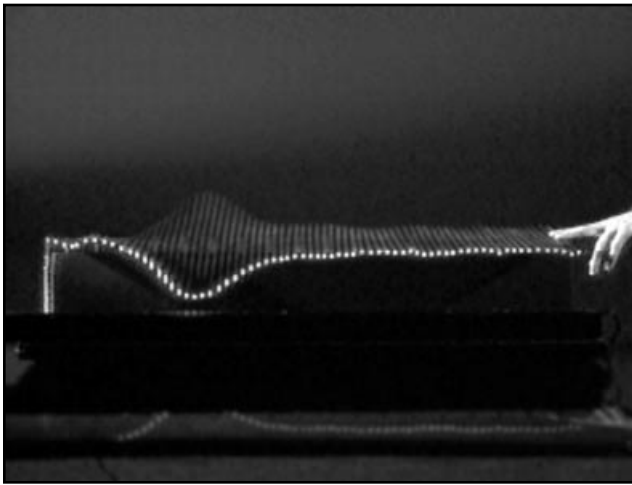


Figure 1

[†] John N. Shive, *Similarities in Wave Behavior* (Bell Telephone Laboratories, third printing, January 1964).

We'll send a torsional wave down this wave machine to show what happens when the wave reaches the end.

When the rod at the end is free to move, the wave reflects back with the same positive amplitude as the incoming wave.

If we fasten the last rod on the machine so it can't move, the reflected wave has an amplitude opposite that of the incoming wave.

Equipment

1. Same as Demonstration 09-16.
2. End clamp.

A wave pulse in a small tight spring is started at the right-hand end of the spring, and allowed to reflect off the left-hand end. When the reflecting end is rigidly fixed, the reflection creates an inversion of the pulse. When the reflecting end is tied to a light cord so that it is free to move perpendicular to the length of the spring, the wave will reflect with the same direction of displacement. These two reflections are shown in *Figure 1* for a positive incoming wave. The top is the reflection from a fixed end and the bottom is the reflection from a free end.

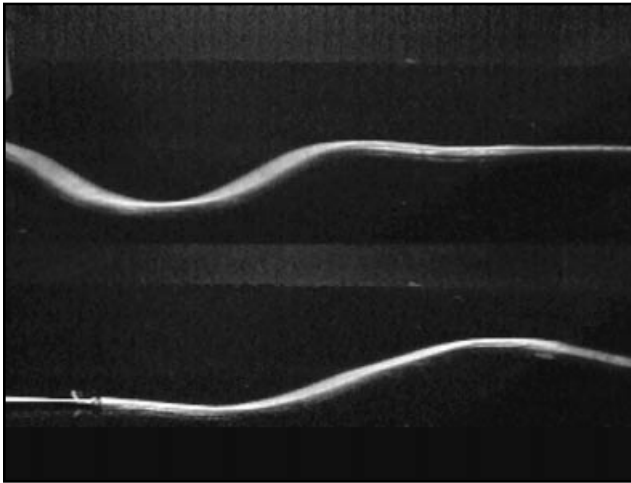


Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration S-24, Wave Reflection at a Change of Medium.

When a wave pulse on a spring reaches the end of the spring, some or all of the wave is reflected.

In this first case, the end of the spring is attached to a rod so that it can't move. Here's how a wave reflects from the end.

We'll repeat that in slow motion.

Notice that the reflected wave is an inverted version of the incoming wave. Now we'll tie the end of the spring to a long, light string so that the end moves freely.

The wave now reflects without inverting.

Let's compare the two types of reflection side-by-side.

Equipment

1. Long brass spring that has a low mass string with a loop tied to the far end of the spring.
2. Clamp and bar:
 - a: slide far end of spring over the bar to show a fixed end, and
 - b: slide the connected string over the bar, after removing the spring itself, which will approximate a spring with a free end.

If two sections of a Shive Wave Machine[†] are connected together and a wave pulse starting at one end propagates across the interface, it will see an impedance mismatch, causing some of the wave to be reflected. If a small tapered section of Shive Wave Machine, shown in *Figure 1*, is used as an impedance matching transformer, the wave pulse will pass through the interface with very little reflection, allowing a greater fraction of the energy of the wave to be transmitted.

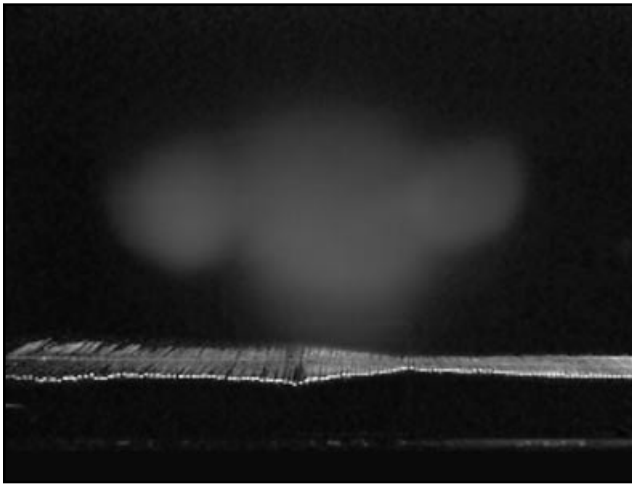


Figure 1

[†] John N. Shive, *Similarities in Wave Behavior* (Bell Telephone Laboratories, third printing, January 1964).

On this wave machine, long rods are attached to a square metal spine at regular intervals. If we tip the first rod sharply, a torsion wave travels down the machine at a constant speed.

This wave machine is identical except that the rods are shorter. Waves moving on this machine travel more quickly than waves on the first machine.

If we hook the two machines together and send a wave along, part of the wave is reflected at the coupling point, and part is transmitted.

This machine has rods that decrease in length from those of the first machine to those of the second.

A wave now passes smoothly through the interface with little reflection.

Equipment

1. Long section of Bell Lab wave machine.
2. Short section of Bell Lab wave machine.
3. Interface section of Bell Lab wave machine (all prepared as previously described).
4. Four or five black lights.

A ripple tank consists of a thin layer of water in which water waves can be created and studied by projecting the motion onto a screen.[†] A layer of clear plastic placed on the bottom of part of the tank decreases the depth of the water, and thus reduces the wave speed. Refraction, or bending of the wave fronts, can be seen as they pass the interface at an angle with respect to the normal, as shown in *Figure 1*.

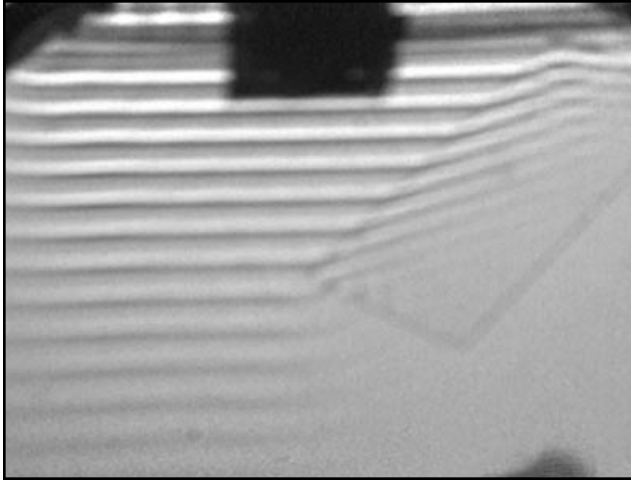


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration S-49, Ripple Tanks.
Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Sm-1, Ripple Tank.

We'll use this ripple tank, which projects an image of waves on the surface of water, to demonstrate the refraction of water waves.

When we put a rectangular pane of glass into the tank, the water over the glass is shallower than the rest in the tank. When the waves cross over into the shallower water, they are refracted to the side.

Equipment

1. Ripple tank.
2. Rectangular plane of glass.
3. Light source.
4. Vibrator system.
5. Projection screen.

A ripple tank can be used to illustrate single slit diffraction of waves.[†] The amount the wave is diffracted—bent or spread out upon passing through the slit—depends on the ratio of the wavelength λ to the slit size a : the greater the ratio λ/a , the greater the diffraction. Several examples are shown, with various wavelength and slit size, two of which are illustrated in the split screen of *Figure 1*.

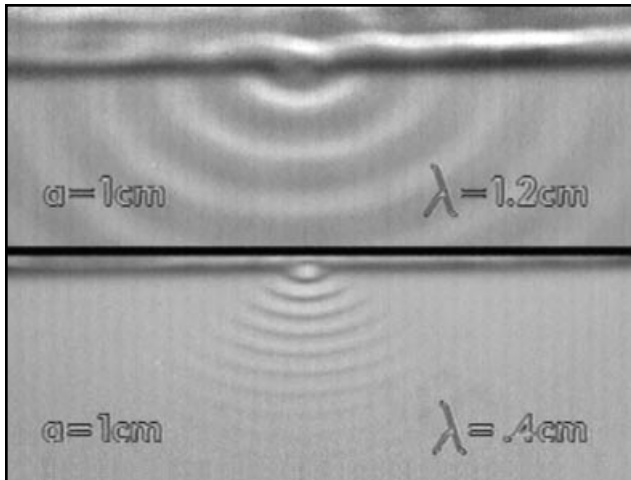


Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstration S-49, Ripple Tanks.
Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Sm-4, Single Slit.

We'll use this ripple tank, which projects an image of waves on the surface of water, to show diffraction through a single slit.

If we put a single slit in front of the waves, the waves emerging from the slit are no longer plane waves. The waves are now diffracted strongly to the sides.

If we decrease the wave length the amount of refraction is reduced.

This split screen view shows the diffraction at two different wave lengths.

Increasing the width of the slit also decreases the diffraction of the wave.

This split screen view shows the diffraction with two different slit widths.

Equipment

1. Complete ripple tank assembly.
2. Single slit apparatus.

A ripple tank can be used to illustrate double slit interference. The interference pattern depends on the ratio of the wavelength λ to the slit separation d . Longer wavelengths or smaller slit separation cause the pattern to spread out, as shown in the video for several examples. Examples are shown for the case of two wavelengths in *Figure 1*.

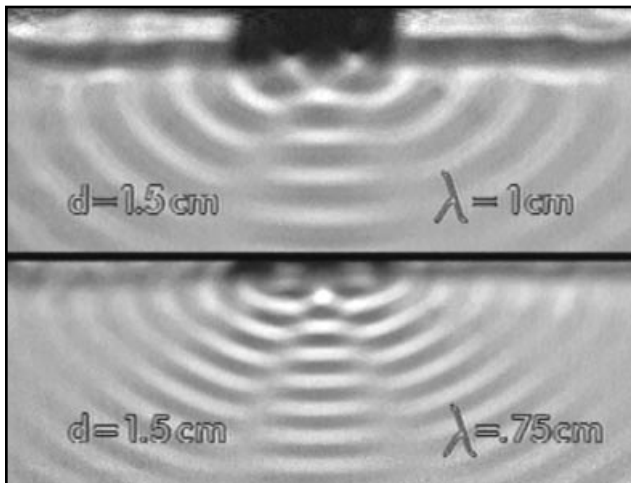


Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration S-49, Ripple Tanks.
Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Sm-5, Double Slit.

We'll use this ripple tank, which projects an image of waves on the surface of water, to show interference of waves from two closely spaced slits. When we put a pair of slits in front of the waves, an interference pattern results.

Decreasing the wave length increases the number of nodal lines in the pattern.

This split screen view shows the patterns resulting from the two wave lengths.

Increasing the separation of the slits also increases the number of nodal lines.

This split screen view shows the patterns resulting from the two slit spacings.

Equipment

1. Complete ripple tank assembly.
2. Double slit apparatus.

Two transparent slides containing sets of equally spaced circles are superimposed on an overhead projector. This effect, shown in *Figure 1*, creates an analog to the double slit interference of sound or light illustrated in Demonstration 22 above for the ripple tank. If the sources are moved closer together, as in the case of the double slit ripple tank experiment, the interference pattern spreads out.

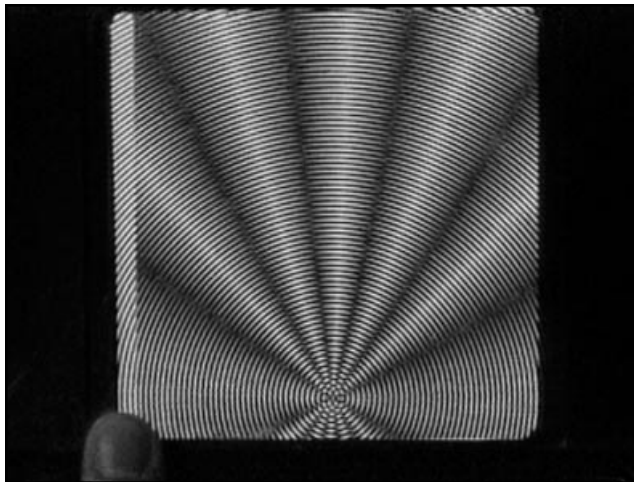


Figure 1

Here are a pair of slides with identical concentric circles printed on them.

We'll use them to simulate the interference of waves from two coherent sources.

If we place the slides one on top of the other, a regular pattern appears.

Moving the centers closer together widens the pattern of light and dark area.

Equipment

1. Overhead projector.
2. Mask for size of slides.
3. Two slides with identical concentric circles.

C H A P T E R 2 2

S T A N D I N G W A V E S

The longitudinal wave machine in Demonstration #14 on this disc can be used to illustrate standing waves. The end bar is moved back and forth at the resonant frequency of the standing wave, creating the standing waves as illustrated in *Figure 1*.

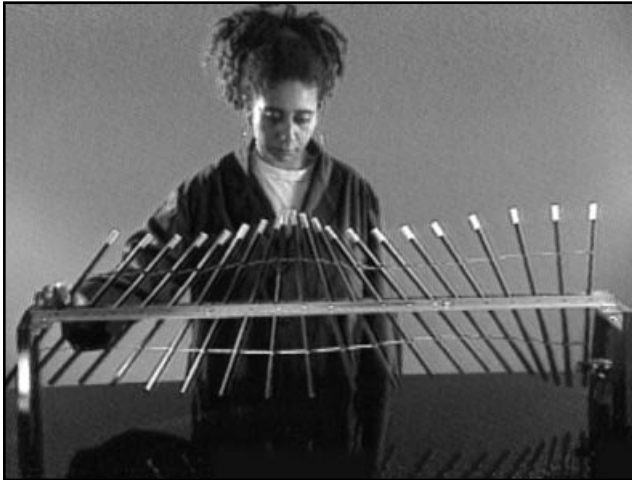


Figure 1

This device is used to demonstrate longitudinal waves, where the displacement of the medium is parallel to the motion of the wave.

When the first rod is pushed sharply, springs between the rods pass the motion along.

If the first rod is moved back and forth at certain frequencies, standing waves appear.

Equipment

Same as Demonstration 09-14, with one end clamp.

The suspended Slinky spring shown in Demonstration #15 on this disc can be used to illustrate standing waves. If the end of the spring is oscillated at the resonant frequency of one of the standing wave modes of the Slinky, a standing wave will be created, as shown in *Figure 1*. Pressure nodes and antinodes are marked on the standing wave. The pressure nodes shown are displacement antinodes, and the pressure antinodes are displacement nodes.

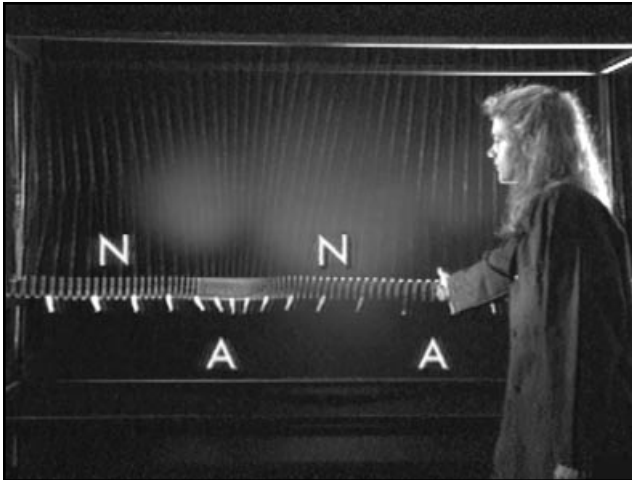


Figure 1

If we push and pull the end of this hanging spring repeatedly, waves of both compression and expansion travel along the spring.

If we push and pull at a certain frequency, a longitudinal standing wave appears on the spring.

Pushing and pulling at a higher frequency creates a standing wave with a shorter wavelength.

The nodes and antinodes of the standing waves have been marked in these slow-motion views.

Equipment

Same as Demonstration 09-15.

The Shive Wave Machine can be used to illustrate standing waves.[†] If one end of the machine is moved up and down at the resonant frequency of a standing wave mode, that standing wave will be created, as shown in *Figure 1*.

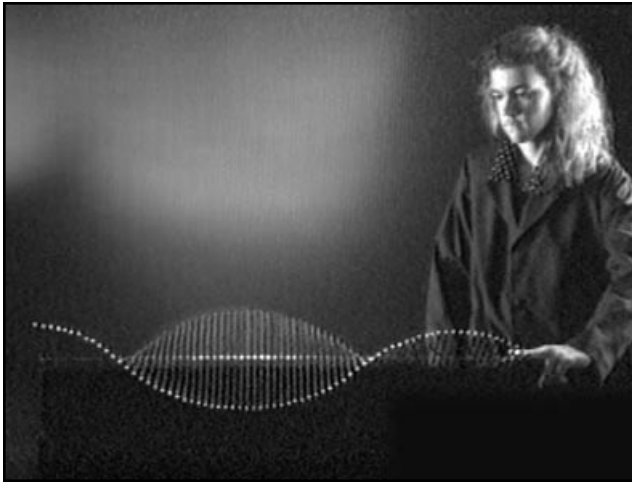


Figure 1

[†] John N. Shive, *Similarities in Wave Behavior* (Bell Telephone Laboratories, third printing, January 1964).

If we send a wave pulse along this wave machine, it is reflected at the end. If we continue sending pulses at regular intervals, and then adjust the frequency until it is just right, the incoming and reflected waves add to form a standing wave.

Increasing the frequency slightly destroys the standing wave. Increasing the frequency even further to just the right value creates another standing wave with a shorter wavelength.

Equipment

1. Short section of Bell Lab wave machine prepared as discussed earlier.
2. Two black lights.

Standing waves of different wavelength can be produced in identical strings by vibrating one end of each tube at the same frequency and hanging different weights on the other end, as shown in *Figure 1*. For any wave in a stretched string, the wave speed S is given by

$$S = \sqrt{\frac{F}{\mu}}$$

where F is the tension and μ is the mass per unit length of the stretched string. The three waves shown are the first, second, and third harmonics, so their wavelengths are $2L$, L , and $2L/3$ respectively, where L is the length of the string. To produce these waves requires a tension that can be determined as follows:

$$f = \frac{S}{\lambda} = \left(\frac{1}{2L} \sqrt{\frac{F_1}{\mu}} \right) = \left(\frac{2}{2L} \sqrt{\frac{F_2}{\mu}} \right) = \left(\frac{3}{2L} \sqrt{\frac{F_3}{\mu}} \right)$$

Thus the ratio of tension required to produce these waves is given by

$$1\sqrt{F_1} = 2\sqrt{F_2} = 3\sqrt{F_3}$$

from which the ratio of masses is 0.9 to 2 to 8, as on the video.



Figure 1

Three strings under different tensions will be used to demonstrate the effect of tension on standing wave formation.

The ends of the strings hang over pulleys, with weights of 0.9 newtons, 2 newtons, and 8 newtons providing the tensions.

All three strings will be driven at the same frequency.

Here are the three standing wave patterns produced.

If we decrease the tension in the center string by lifting up on its weight, its standing wave pattern changes to match that of the lower string.

If we increase the tension in the center string by pulling down on the weight, its standing wave pattern changes to match that of the upper string.

Equipment

1. Motor-driven can vibrator.
2. Three lengths of strings with one end tied to the vibrator and the other ends passing over three separate distant pulleys.
3. Support system for three pulleys.
4. Appropriate weights for each of the three strings.
5. Several clamps.

A variable frequency motor is used to vibrate the end of a long rubber tube, creating standing waves,[†] as seen in *Figure 1* for the third harmonic mode. Several standing waves are shown, and the nodes and antinodes identified for each.



Figure 1

[†] Sutton, *Demonstration Experiments in Physics*, Demonstrations S-10 and S-33, Wave Machine. Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Sa-9, Standing Waves.

We'll now show standing wave formation resulting from different driving frequencies.

This rubber tube is put under tension by a weight hanging from the end.

A beater strikes the end of the tubing at an adjustable frequency.

At a very low frequency, the tubing hardly reacts. But as the frequency is raised, the fundamental of the tubing is excited and the amplitude increases greatly.

If we increase the frequency, the fundamental disappears. As we continue to increase the frequency, we excite the second harmonic.

We continue to raise the driving frequency, and strike the third harmonic.

Here are some of the higher harmonics in slow motion.

Equipment

1. Variable speed motor control.
2. Vibrating assembly.
3. Length of rubber tubing.
4. Free-wheeling pulley
5. Hooked weight.
6. Clamps to hold everything securely.

A variable frequency oscillator and a loudspeaker positioned underneath a drumhead are used to excite the resonances in the drumhead. Several modes are shown, including symmetric modes and antisymmetric mode shown in *Figure 1*.



Figure 1

Have you ever wondered how the head of a drum vibrates when it is struck? We'll use this flexible rubber diaphragm and this speaker to show some of the forms of vibration.

The speaker drives the rubber drumhead with sound waves from beneath.

Here is the fundamental vibration of the drumhead, seen with a strobe light to slow down the motion.

Here is an oscillation at a higher frequency. Notice the circular nodal line.

Here is a different type of oscillation, with a nodal line running across the diameter.

Equipment

1. Rubber diaphragm.
2. Speaker.
3. Audio oscillator.
4. Strobe light.

A square black anodized aluminum plate is excited in its center by vibrations in the 20 kilohertz range originating from magnetostriction in a thin-walled annealed nickel tube. When the oscillator creating the oscillating magnetic field is tuned to a resonant frequency of the aluminum plate, standing waves are formed.[†] These standing waves can be viewed by sprinkling sand onto the plate, because the sand will quickly drift to the nodal lines, as shown in *Figure 1*. Several examples are shown and the frequency of each displayed on the screen with the standing wave pattern. This type of oscillation also occurs in the back and the belly of a violin, enhancing the intensity of higher harmonics in the violin tone.

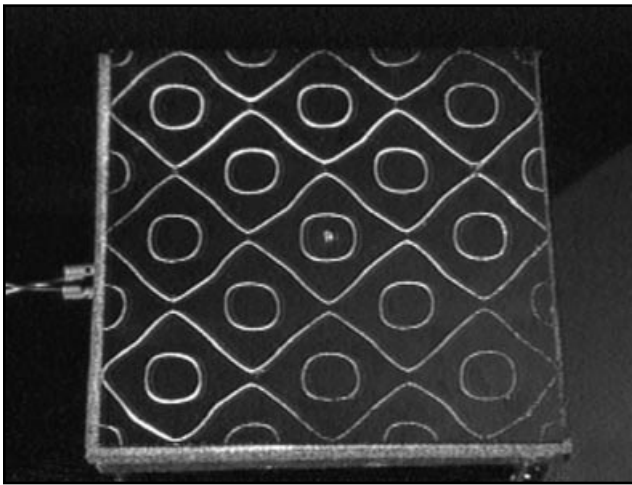


Figure 1

[†] E. R. Pinkston, Lecture demonstration of nodal patterns, *Am. J. Phys.* 14, 138 (1946).

In this demonstration we will observe standing wave vibrations of an aluminum plate.

An oscillator in the 10 to 30 kilohertz range produces sine waves which are amplified by this audio amplifier and fed into this small coil.

A piece of thin-walled annealed nickel tube is mounted rigidly to this black anodized aluminum plate, and the tube is inserted into the coil. The process of magnetostriction in the nickel tube converts magnetic oscillations of the coil into mechanical vibrations.

The frequency is set, as shown by the inset at the lower left of the picture, and sand poured onto the plate. The sand illustrates the standing wave pattern by gathering along the nodal lines.

Now the frequency is adjusted to show various standing waves in the plate.

The wooden plates on a violin would exhibit this type of oscillation.

Equipment

1. Square, flat black plate attached at its center to a thin-walled annealed nickel tube.
2. Support assembly for plate with small electric coil on its underside, located at the center hole.
3. Audio oscillator.
4. Amplifier.
5. Supply of sand.