Mechanical Wave Complete Bundle

P7-1100

INSTRUCTIONAL GUIDE

Contents

The Arbor Scientific Mechanical Wave Complete Bundle comes with everything you need to drive wave experiments and harmonic and motion demonstrations with ease and accuracy.

a. Mechanical Wave Driver
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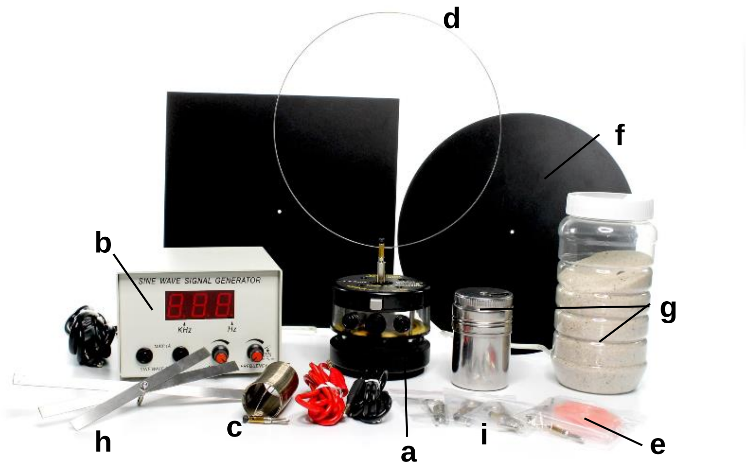
e. Transverse Wave String
f. Chladni Plates Kit
g. Sand and Shaker
h. Metal Resonance Strips
i. Holders and Mounting Hardware



Recommended for activities:

- Ring Stand (66-4220)
- Buret Clamp (66-8002)
- Table Clamp Pulley (P1-6115)
- Digital Newton Meter (01-7000)
- Hooked Mass, Set of 9 (91-1000)

Mechanical Wave Driver (P7-1000) – Our electromechanical driver is an ideal device for harmonic and motion demonstrations. Its primary function is to provide variable frequency, variable-amplitude and mechanical vibrations for the lab.

Sine Wave Generator (P7-2000) – The Sine Wave Generator allows control for both the frequency and amplitude of the sine wave output. Students can observe the quantum nature of standing wave patterns as the Sine Wave Generator jumps from one resonant frequency to the next.

Longitudinal Wave Spring (P7-1500-01) – Experiment with springs, oscillations, and wave theory! A great way to demonstrate and visualize the nodes and antinodes on longitudinal waves.

Resonance Wire Loop (P7-1500-02) – Introduce Bohr's quantum atom using a classic model. The resonance wire loop demonstrates standing wave patterns when vibrated at resonant frequencies.

Transverse Wave String (P7-1500-03) – This Wave string is ideal for demonstrating standing waves. Typical experiments such as the resonant frequencies of taut vibrating string can be performed with additional parts.

Chladni Plates Kit (P7-1500-04) – The first step to Visualize Acoustics! At special frequencies, standing waves appear on the plate, driving the sand away from the points of large vibration to points of no vibrations. Unique patterns are formed at different resonance frequencies becoming increasingly complex and beautiful as the rate of oscillation increases.

Metal Resonance Strips (P7-1500-05) – Demonstrate resonant modes as a function of length. As vibration frequency increases, shorter length strips reach resonance and visibly oscillate.

Activities

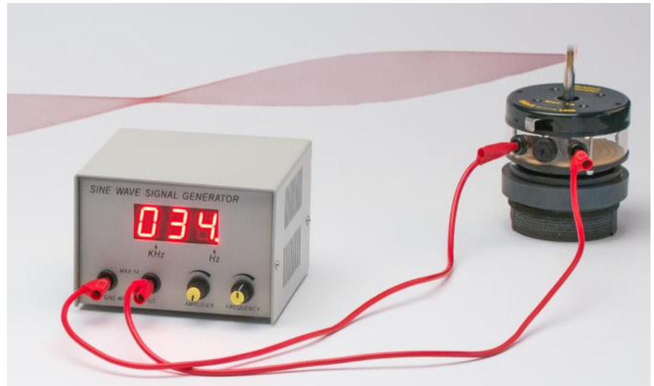
Longitudinal Wave Spring (P7-1500-01)
Demonstrate longitudinal standing waves on a stretched spring.

Resonance Wire Loop (P7-1500-02)
Produce standing waves on a wire loop to explain the atomic model's electron orbitals.

Transverse Wave String (P7-1500-03
Dramatic node and antinode patterns make it easy to measure the wavelength, amplitude, and speed of the waves.

Chladni Plates Kit (P7-1500-04)
Vibrate the plates and observe the standing wave patterns. Sand collects in the nodal regions and forms sharply distinct lines of destructive interference against the black metal.

Metal Resonance Strips (P7-1500-05)
Demonstrate the principle of resonance between the frequency of the driver and the standing waves that form on different length metal strips.



The Mechanical Wave Driver is a heavy duty long-throw speaker that can vibrate with variable amplitude and frequency. Attached to the middle of the speaker cone is a metal drive shaft, which can be used to drive a wide variety of wave and resonance experiments. You will need a function generator or sine wave generator producing a current of up to 1 ampere in conjunction with the wave driver.

The Sine Wave Generator is an excellent tool for generating waves with speakers or our mechanical wave driver. It allows both the frequency (1-400 Hz/1 Hz resolution; 10-4000 Hz/10 Hz) and amplitude of the sine wave output to be varied. Students can observe the quantum nature of standing wave patterns as the Sine Wave Generator jumps from one resonant frequency to the next.

Set-Up

Set up the apparatus following the steps outlined below:

1. Lock the drive shaft by sliding the locking lever to the “Lock” position. This protects the speaker from being pulled or pushed too far when connecting or disconnecting apparatuses to the drive shaft. *It is important to unlock the drive shaft when running your experiments.*
2. After connecting a banana plug holder to the wave demonstration apparatus, insert the banana plug holder on the apparatus into end of the drive shaft.
3. Unlock the drive shaft locking arm and connect the output from the sine wave generator to the wave driver input with banana plug patch cords.
4. Using the output knobs on the sine wave generator, adjust the frequency and amplitude to produce mechanical vibrations to drive your experiments.

Longitudinal Wave Spring

Longitudinal standing waves are common in many different mediums; gases liquids and solids. When a wave train moves through a medium and encounters an end or boundary, some portion of the wave energy will be reflected backward. If the original source of the waves continues, the medium will quickly fill with waves traveling back and forth over each other. At specific frequencies the displacements of these waves will combine to produce a steady-state interference called a standing wave. If the disturbance is produced in a long spring by a back and forth displacement in the same direction of the spring, the coils will be compressed and stretched producing a longitudinal standing wave

Activity

Set-Up:

1. Attach the banana plug connector to the spring by hooking one end of the spring through the hole in the plug.
2. Insert the banana plug into the shaft of the Mechanical Wave Driver.
3. Attach the other end of the spring to a ring stand clamp. Raise the clamp, stretching the spring upward 40-50 cm. To quantify the tension of the spring, a Digital Newton Meter (01-7000) may be added between the spring and clamp.
4. Connect the Mechanical Wave Driver to a Sine Wave Generator.

With the amplitude of the Sine Wave Generator turned low, turn on the generator, starting with a low frequency of about 5 Hz output to Mechanical Wave Driver. Increase the amplitude and gradually increase the frequency until nodes and antinodes form along the spring.

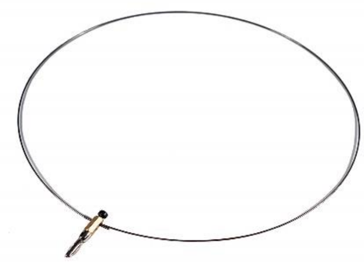
The nodes will appear where sections of the spring appear motionless while the antinodes appear as a blurred agitation. Measuring the spacing from node to node or antinode to antinode will give a value equal to half the wavelength of the standing wave. Recall that speed is distance over time:

$$speed = \frac{distance}{time}$$

Waves also have properties of distance (wavelength) and time (frequency). Therefore, we can determine the speed of a wave with a simple equation. Write the formula for wave speed (*v*) in terms of wavelength and frequency. Remember that frequency has units of *1/s*.

$$v = \lambda \cdot f$$

Try increasing the frequency of the generator until the next standing wave pattern forms on the spring and notice how the spacing pattern changes. With this new spacing and frequency, again calculate the wave speed as above and compare it to your first calculation.



The Wire Loop provides a way of demonstrating standing waves on a circular wire. It can be used to explain the energy levels for electron orbits in an atom. The wavelength of a wave traveling in a medium is determined by the wave speed in the medium and the frequency of the disturbance producing the waves. When a whole number of wavelengths just fit in a medium of fixed length, the waves can add together to produce a standing wave pattern.

In the wire loop, the speed of the waves around the wire is a function of the wire's density and stiffness. As the wire is vibrated, the wavelength will decrease as the frequency increases. When a frequency is reached that produces full waves that just fit around the wire, consecutive waves will add together to produce a standing wave along the wire. Higher frequencies, which are multiples of the lowest standing wave frequency, will produce standing waves of shorter lengths with increased numbers of nodes and antinodes. The wire loop will form a standing wave at specific frequencies: each one corresponding to a unique wavelength.

An important application of these standing waves is in understanding electron orbits in the Bohr model of atoms. Each Bohr orbit corresponds to a standing wave configuration for an electron.

Set up:

1. Insert the banana plug that is holding the two ends of the wire loop into Mechanical Wave Generator shaft as shown above.
2. Connect the Mechanical Wave Driver to the Sine Wave Generator using the two banana plug cables

Activity

Set the frequency of the Sine Wave Generator to 5 Hz and slowly turn up the amplification nob causing the wire loop to vibrate. Slowly increase the frequency until a standing wave begins to form. Continuing to increase the frequency will cause the standing wave to disappear until standing waves with shorter wavelengths form at higher frequencies.

Wave interference occurs when two longitudinal waves interact and either constructively increase amplitude or destructively decrease amplitude. The observed overlapping appearance is called an interference pattern. For instance, when formed along a one-dimensional rope or spring, this can produce a pattern called a standing wave. Tie a rope to a wall and shake it and the wave reflected from the wall will come back and interfere with the following waves moving toward the wall. At the right frequencies, nodes will form where the interfering waves cancel out and anti-nodes will form where the waves create larger amplitudes. Going further, the students can directly measure the length of the waves from the standing wave pattern and confirm the wave equation $v=\lambda f$ using the frequency value from the Sine Wave Generator. With the wavelength and the frequency, the speed of the waves along the string can be calculated. Later this speed value can be compared to theoretical speed calculated from the physical properties of the medium (string).

Activity

Set up:

1. Fasten the neon red string to a fixed post or ring stand making sure it is slightly higher than the Mechanical Wave Driver.
2. Thread the string through the hole in the string holder inserted in the Wave Driver.
3. Fasten a **Table Clamp Pulley** on a ring stand approximately 2 meters from the string holder.
4. Thread the string over the pulley making sure it is clear of the table and attach a **hooked mass**.

Your students will use the wave equation $v=\lambda f$ to calculate and predict the speed of the waves traveling back and forth along the string. After the apparatus is set up as shown above, the frequency and amplitude of the driver can be adjusted to produce standing waves with maximum amplitudes.

Observations

Measuring wave speed along the string: Start at a low frequency and slowly increase the value through turning the frequency nob. The frequency which produces the longest standing wave is called the fundamental and has the appearance as shown in the diagram below.

Fundamental

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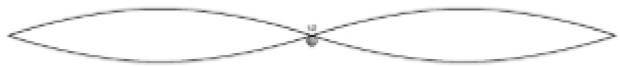
At this lowest standing wave frequency, called the fundamental, the length of the standing wave is twice the length of the string. The fixed ends of the string are points called nodes and the center of the string, where the string moves up and down with maximum amplitude is called the antinode. Now increase the frequency until the next standing wave appears. This should occur at a frequency twice the value of the fundamental frequency and is known as the second harmonic. As shown below, there should now be two antinodes formed.



2nd Harmonic

The distance from antinode to antinode or from node to node is half a wavelength. Have the student measure and record either of both of these lengths. If both are measured, average their value and multiply it by two to get the wavelength. From the display on the Sine Wave Generator record the frequency producing this standing wave.

frequency (2nd harmonic) _________ Hz   Wave length __________ m

Calculate the wave speed from the wave equation showing the substituted values:

v = (   ) x (   ) = _______ m/s

Now, increase the frequency of the generator to produce standing waves of higher frequency and shorter wave length. If the length of string and tension have not been changed the wave speed should remain relatively constant. Using the same procedure above, measure and calculate the wave speed again.

Within the uncertainty of measurements, how do these new values compare?

Going Further

The speed of the waves on the string in the above experiment is determined by the physical characteristics of the string. That is, the string density (m/L) in kg/m and the string tension (T) in Newtons.

The equation that relates these values is:

speed = tension x *string density*

The string tension (T) is produced from the weight of the hanging mass as shown in the diagram. For instance, if a 100 g mass is used, the tension represented by “mg” would be 0.98 N. For the linear string density, measure the length (L) of the string and divide it by its mass (m). Record these values below and calculate the predicted wave speed.

T = _________ N   m = _________ kg   L = _____________ m

Calculate the Wave Speed: (show the equation and substitution below)

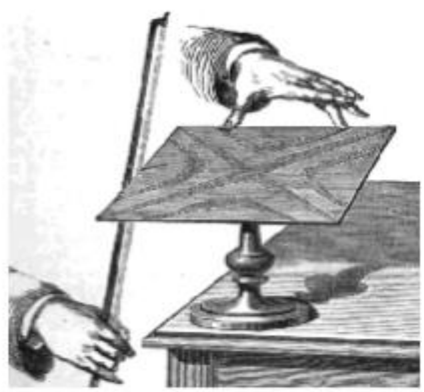
v = __________ m/s

German physicist Ernest Chladni (1756-1827) observed that metal plates display patterns as they vibrate and described this result as a function of harmonic frequencies. It is a lesson in standing waves in two dimensions; vibration in the plate sets up a pattern based on the frequency and how it is reflected at the ends. However, not every frequency causes a pattern because not every wavelength fits on the plate. Resonances occur at different frequencies and that there are several possible.

If you are going to reference standing waves, it is important to note that the end points are anti-nodes. You will notice that the sand never builds up along the rim of the plates because that is the location where the wave is vibrating the most. This is different from guitar strings because the ends are nodes; the process is to waves on a hanging string or waves in a double open instrument, such as an oboe, pan pipe, or **Boomwhacker**.

Introduction

Originally the plate was driven with a violin bow. This method has its downsides, because it can be difficult, limits your frequency options, and requires a lot of practice. Now, the Chladni Plate is vibrated with a mechanical driver.



An early illustration of a Chladni Plate. Note that the thumb and fingers are used to help place the nodal lines where little movement occurs.

To start, secure the metal clip through the plate and attach it to the Mechanical Driver shaft. The connection must be very secure to transmit the vibrations. A medium amplitude should work for most resonances. Several patterns will be produced. These standing waves are made visible with sand because the amplitude is largest at the antinodes which pushes the sand away toward nodes to create “nodal lines.”

Experimenting

It is helpful to secure the drive shaft and use medium amplitudes as you search for resonances. Move through a range of frequencies while adding small amounts of sand until you think you have found one. A larger amount of sand may change the effective mass of the plate and cause the frequencies to vary. Try to balance the plate and driver so that little sand pours off the edges.

The lower frequencies are further spaced, but the higher frequencies are more complex and beautiful.

The speed of sound can be measured in the plate itself. Find the frequency from the driver and then measure the wavelength as a node to node (sand to sand) distance.

A reasonable question to discover is “Is the Speed of Sound Constant in the Plate?” The reason that the speed of sound might not be constant is that at higher frequencies and higher amplitudes, the plate vibrates non-linearly. (This is similar to how a prism separates light by color; the speed of light waves is different at different frequencies.)

However, in the plate, the effect can even be complicated more by the damping of the wave. A wave that is vibrating in a medium that reduces its amplitude measurably as it travels is said to be “damped.” A good example is how a guitar string will vibrate for a long time after being plucked, unless you put your finger on it, which causes it to dampen faster. Also, some bells dampen faster than others. Higher frequencies tend to dampen more quickly, too.

If several students are performing the experiment, it might be a good idea to have the students take pictures of the various patterns they produce and note the frequency. Then they can create a (digital) portfolio of their results.

Measuring with the round plate should generate results that are more faithful to the “speed of sound is constant” model. This will be visible in the nodes (white stripes) being equally spaced.

Conclusions

The Chladni Plate provides an opportunity to teach an advanced concept in the Physics of Sound while at the same time performing a demonstration that is visually stunning. The idea of nodes and antinodes (and the idea that these reveal wavelength) should be emphasized throughout the lesson.

A common missed opportunity is to quantify this experiment, and reinforce the v=f formula. The details of the Chladni rules may only serve to over complicate this demonstration, but might be appropriate in an advanced class on the Physics of Sound. (See references for more details on these.)

Metal Resonance Strips

Resonance is the condition in which energy is transmitted between two oscillating objects. Resonance occurs when one is the driving force and its frequency is varied until it matches a natural frequency of the other oscillating object. The metal strips in this apparatus have natural frequencies of oscillation related to their length.

A time-dependent driving force is provided by the Mechanical Wave Driver. When the frequency of the wave driver matches a natural frequency of the metal strips, a standing wave pattern will form in the metal strips. Since the length of the standing waves must be matched to the length of the metal strips, resonance will occur at different frequency for different length strips. While one strip resonates with large amplitudes, the other metal strips will appear almost motionless. The nodes and antinodes along the resonating strip are clearly apparent and their wavelengths can be measured.

Set-Up

1. Rotate the metal strips so that they are at equal angles from each other.
2. Insert the banana plug of the metal strip into the driver shaft of the Mechanical Wave Driver.
3. Connect the Mechanical Wave Driver to the sine wave generator using two banana plug cables.

Activity

With the amplitude of the Sine Wave generator turned low, start with a low frequency of about 5 Hz output from the function generator to the wave driver. Increase the amplitude, and gradually increase the frequency until resonance occurs in the longest strip. Continuing to increase the frequency will establish resonance with the shorter strips.