PHYSICS DEMONSTRATIONS IN SOUND & WAVES

PART II

Good intro. on sound.

Demonstration No. 1
Nature of Sound Waves: Sources and Propagation of Sound
Length: 3:51 minutes / Location: 00:45 - 4:36 minutes

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speed of sound experiment c oscil times.

Objective:
To gain an understanding of how sound waves are produced and the way in which sound waves propagate through a medium.

Using the Demonstration:
The term "sound" refers to the physical sensation that stimulates our ears, namely, longitudinal waves of a certain frequency range. In order to understand the process by which sound is produced, a vibrating tuning fork is examined. Its pure tone--ability to vibrate at a single frequency with no harmonics--makes the tuning fork a desirable sound source to work with.

A better picture of how a tuning fork produces sound is obtained by viewing it with stroboscopic illumination. With the strobe flashing at a frequency slightly different from that of the tuning fork, we see successive "snapshots" of the vibrating fork taken at progressive points during its cycle. This slow motion effect allows one to clearly see the vibratory motion of the tuning fork, as well as the unexpectedly large periodic displacement of the vibrating prongs. It becomes apparent that sound is created by a vibrating source; virtually any object can vibrate in some manner and therefore be a source of sound.

By using computer animation to visualize the air molecules surrounding the tuning fork, a sound propagation model is presented. As the tuning fork vibrates, it is seen to alternately compress and expand the air immediately in front of it, causing the air pressure to alternately increase and decrease. As the cycle continues, the pressure fluctuations propagate through the air in the form of a longitudinal wave. Although the sound waves travel outward, the air molecules themselves are not carried along with the wave, but merely oscillate back and forth about their rest position. It should be noted that the frequency of the sound waves is the same as the frequency at which the tuning fork vibrates.

In order to find evidence which supports the model that sound propagates by means of pressure waves, a speaker and a narrow diameter gas jet are used. The speaker is driven by a signal generator set at a frequency of 120 Hertz. Flammable gas is fed into a glass nozzle which is drawn out to produce a narrow opening. Igniting the gas produces a tall stable flame. With the gas pressure increased to the point where the flame is on the verge of becoming unstable, an instrument known as a sensitive flame is created. A sensitive flame is useful due to the fact that it is very responsive to pressure changes in and around the flaming gas.

With the sensitive flame positioned directly in front of the speaker, the frequency generator is turned on. As the speaker vibrates, the sound waves which are emitted cause the flame to be disturbed as it is shortened and pushed away from the sound source. The sound waves traveling through the flaming gas create pressure changes within the gas, causing the flame to become turbulent. This gives supportive evidence that sound travels through air by means of pressure waves.

With the flame extinguished, it is shown that it is not the flame which is affected by the sound wave, but rather, what is being affected is the gas itself. By directing an intense source of light through the gas and onto a screen, the narrow stream of upward flowing gas can be seen due to refractive differences between it and the surrounding air. With no flame present, the emitted sound wave is observed to cause the gas column to become turbulent. Here again, the result is due to sound waves traveling through the gas and creating pressure changes within it.

Teaching Notes:

- Stroboscopic illumination can be used on many high frequency sound sources to make visible (or visually enhance) the vibratory motion of the source.
- From viewing a textbook illustration alone, students may get the impression that the medium travels along with the sound wave (that is, sound waves propagates in a manner which would be equivalent to simply moving the entire text illustration along one direction). The tuning fork/sound wave computer animation is useful in clearing up this misconception. The teacher may wish to show the animation a couple of times and have students initially focus on the outward moving wave, observing how momentum is transferred from molecule to molecule all down the line. Secondly, have students keep their eyes fixed on a single molecule to observe its oscillatory motion about its rest position. (It is instructional to show the animation frame by frame if an appropriate video player is available.)
- It should be pointed out that the computer animation is a one-dimensional model of a sound wave as actual sound waves will propagate outward in all directions.
- For a sound wave, the amplitude of the medium's oscillatory motion is extremely small compared to the wavelength. The loudest sound waves which the ear can tolerate without pain have maximum amplitudes (distance which the air molecules have moved from equilibrium) on the order of 1/100 millimeter at 1000 Hz. The displacement amplitude in the faintest audible sound is on the order of 10^{-11} meters – a displacement which is actually less than the diameter of the atoms themselves!

Demonstration No. 2

Propagation of Sound: Direct Measurement of the Speed of Sound in Air and Metal

Length: 3:59 minutes / Location: 4:53 - 8:52 minutes

~~evaluated~~ measurements c̄ mics & oscilloscopes

Objective:

To experimentally determine the speed of sound in air and aluminum. Using an oscilloscope to measure the time required for sound to travel a known distance, a direct measurement of velocity will be made.

Need to explain this one before shown it.

Using the Demonstration:

Various indirect methods can be used to measure the speed of sound in air such as measuring the wavelength of a known frequency source. However, the direct measurement of the speed of sound, which involves measuring the time required for sound to travel a known distance, instills a tangible sense as to the speed with which sound travels between two points. The extremely short time intervals which are measured impress on the student the large magnitude of this velocity.

The experiment is set up with two microphones separated by a known distance in order to detect the sound at the origin and at the end point of the distance interval. In order to measure the extremely short time intervals which are involved, an oscilloscope is used as a timing device. The microphone which is positioned at the sound source is plugged into the oscilloscope's external trigger; upon detecting the sound, it will start a single sweep of the beam across the oscilloscope screen (at a given sweep rate). The microphone which is positioned at the receiving end, or end point, of the distance interval is plugged into the oscilloscope's vertical input; upon detecting the sound it will initiate a vertical deflection in the beam, thus marking the time interval on the scope's screen.

Initially, the oscilloscope is "zeroed" by bringing the two microphones together such that the distance interval between them is essentially zero. Sound produced by tapping two metal rods together is detected by both microphones at the same time, so that the triggering and receiving of sound happen simultaneously. This zero time shows up on the oscilloscope screen with the leading edge of the received signal at the left-most point on the scale. This marks the starting point of the horizontal sweep as well as the zero time point on the oscilloscope screen.

Next, the receiving microphone is moved to a distance of 2.5 meters from the triggering microphone. The oscilloscope is then used to measure the time required for sound to travel this distance through air. With sound produced at the position of the triggering microphone (by again tapping together two metal rods), it quickly travels through the air and arrives at the receiving microphone in an imperceptible amount of time. The arrival of the sound pulse at the receiving microphone is clearly observed on the oscilloscope screen. The leading edge of the received signal is shifted to the right due to the time required for sound to travel from the first microphone, the triggering point, to the second microphone, the receiving point.

Knowing the rate at which the beam moves across the screen, or sweep rate, the time interval is easily determined. With the sweep rate set at 1.0 millisecond per division (1.0×10^{-3} sec/div), the 7.3 divisions observed between the trigger point and receiving point give a time interval of 7.3×10^{-3} seconds:

$$\text{time interval} = (7.3 \text{ divisions}) \times (1.0 \times 10^{-3} \text{ sec/division}) = 7.3 \times 10^{-3} \text{ seconds}$$

This is the amount of time it takes sound to travel 2.5 meters:

$$v = \frac{d}{t} = \frac{2.5 \text{ meters}}{7.3 \times 10^{-3} \text{ seconds}} = 340 \text{ meters/sec}$$

Which leads to a velocity of 340 meters/sec. Note that this value is the velocity of sound in air at room temperature.

In order to compare the velocity of sound in air to its velocity in a solid material, the same experiment is performed again using a 2.5 meter solid aluminum rod in place of air. Tapping the rod's end initiates a sound pulse in the metal rod and causes the triggering microphone to start the oscilloscope sweep. The receiving microphone at the other end detects the sound pulse after it has traveled through the full length of the rod. With the sweep rate still set at 1.0 millisecond per division, a very short time interval is measured as the sweep moves through only 0.50 divisions before the receiving microphone picks up the sound pulse:

$$\text{time interval} = (0.50 \text{ divisions}) \times (1.0 \times 10^{-3} \text{ sec/division}) = 0.50 \times 10^{-3} \text{ seconds}$$

$$v = \frac{d}{t} = \frac{2.5 \text{ meters}}{0.50 \times 10^{-3} \text{ seconds}} = 5000 \text{ meters/sec}$$

Dividing distance by time yields a remarkable value of 5000 meters/sec for the velocity of sound in aluminum. This velocity is 15 times greater than the velocity of sound in air!

Teaching Notes:

- On the oscilloscope screen, the signal which is detected by the receiving microphone is seen to have a sharp onset (which marks the arrival of sound) followed by a somewhat erratic trace which diminishes in intensity over time. The erratic trace is simply a display of the sound pulse created by tapping the metal rods together – a pulse which lasts for a short period of time. This should not distract students from focusing on the onset of the pulse which is the only point of interest for measuring the time interval.
- The accepted value of the velocity of sound in aluminum is 5100 meters/sec. (The velocity of sound in a number of different metals is very close to this value.)

- Note that in the speed of sound measurement for the aluminum rod, the receiving microphone does in fact pick up sound traveling through the aluminum rod as well as sound which travels through the air. Fortunately, sound travels with a much greater velocity through aluminum than air; therefore, the initial signal which is received by the microphone is that of sound traveling through the aluminum rod.
- In measuring the time interval for sound traveling through the aluminum rod, a faster sweep rate would be desirable if a higher degree of accuracy was required. (Reading 0.5 divisions on a scale offering 10 divisions is not ideal for obtaining a highly accurate result.) However, the sweep rate was kept at the same setting as that used for the speed of sound in air measurement so that a striking visual comparison could be made between the two time intervals.
- Sound waves are generally transmitted more quickly in solids than in gases due to differences in the way atoms interact in the two states. In a solid, the displacement of an atom is transmitted to a neighboring atom through mutual interatomic forces, thus causing longitudinal waves to propagate quickly. In a gas, sound waves are able to propagate only through occasional random collisions between atoms, a comparatively slow process.

Demonstration No. 3
Transmission of Sound Through a Medium: Attenuation of Sound in a Vacuum
Length: 2:11 minutes / Location: 9:11 - 11:22 minutes

Objective: Bell Jar evacuation

To give evidence to the fact that sound waves require a material medium in order to propagate.

Using the Demonstration:
When sound travels through a solid, liquid, or gas, it is the material medium itself which sustains longitudinal waves, thus allowing sound to propagate. This can be substantiated by allowing a sound source to vibrate in the absence of any material medium and observing the result.

In this classic demonstration, an electric bell is placed inside a thick-walled glass container. With the glass container making an airtight seal with the base, a vacuum pump is used to evacuate the air from the container, creating a near perfect vacuum. By suspending the electric bell in such a way that vibrations cannot be transmitted through the mounting apparatus, the only sound waves which are transmitted are those which travel through air.

With the air in the glass container at normal pressure, the ringing bell is clearly heard. The sound waves emitted from the bell travel through the air in the container, through the glass wall, and into the air outside the glass container where they are picked up by a microphone.

Next, the vacuum pump is turned on and allowed to run for a short period of time. With only a portion of the air removed from the glass container, the ringing bell is once again heard. This time, however, the intensity of the sound from the bell is decreased. With fewer air molecules in the glass container, and with greater distances between neighboring molecules, the longitudinal sound waves are transmitted with diminished intensity.

The experiment is continued by allowing the pump to run until a nearly perfect vacuum is created within the glass container. With virtually all the air removed, the ringing bell becomes inaudible. Although the hammer can be seen striking the bell, no sound waves exist within the vacuum. It becomes very apparent that sound cannot travel in the absence of matter, but requires a material medium for the propagation of longitudinal waves.

Teaching Notes:

- In performing this experiment, the way in which the bell is mounted inside the jar is of utmost importance if sound is to travel only through air and not through the mount itself. The mount used in this demonstration consists of a stand that is attached to the bell using alternating layers of rubber and styrofoam.
- Some of the attenuation in sound energy that is noticed when the bell jar is evacuated is due to the mismatch in impedance between the air in the room and that which remains in the bell jar.
- It is important to stress that sound waves, water waves, and waves on a rope or spring, all come under the classification of mechanical waves as all require a material medium for their propagation. If electromagnetic waves have not yet been studied, students should be advised to not jump to conclusions and presume that all waves require some kind of material medium.

Demonstration No. 4
Refraction of Sound: Carbon Dioxide Sound Lens
Length: 3:20 minutes / Location: 11:41 - 15:01 minutes

Objective: Refraction air + CO_2 balloon

To observe the refraction of sound upon encountering a medium change of air to carbon dioxide.

Using the Demonstration:

In order to observe the refraction of sound, a sound source is used which consists of a speaker positioned at the focal point of a parabolic reflecting surface. With the signal generator set at a frequency of 4000 Hz, the short wavelength sound is reflected into a parallel beam of uniform intensity. (At any given distance from the reflector, the sound intensity is uniform throughout a cross-section of the beam.) By using a microphone connected to an oscilloscope, the intensity of the sound can be probed at different locations. Moving the microphone throughout a cross-section of the beam shows that the sound intensity is in fact uniform, as the oscilloscope screen displays a constant signal of moderate amplitude.

If a balloon filled with air is inserted in the sound path directly in front of the microphone, the oscilloscope shows no change in intensity. Moving the microphone from side to side behind the air filled balloon also shows no significant change in sound intensity. However, if an identical balloon of the same size filled with carbon dioxide gas is inserted in the sound path, the microphone detects a large increase in sound intensity. With the air filled balloon not showing this result, the increase in intensity must be attributed to the CO_2 gas within the balloon and not the balloon itself.

On further examination, it is found that if the microphone is moved outward from the center of the CO_2 balloon, the sound intensity drops off sharply and goes to zero near the balloon's edge. This is an area were sound previously existed with the air filled balloon, but now shows an absence of sound with carbon dioxide. Beyond the edge of the balloon, the sound intensity increases as the microphone is no longer behind the balloon and receives sound directly from the source. Moving back in the other direction, the sound intensity reaches a maximum directly behind the center of the CO_2 balloon, and again drops off to zero as the other edge of the balloon is approached.

This pattern of changing sound intensity can be explained by viewing the carbon dioxide balloon as a spherical sound lens. Sound waves emitted by the source travel slower in the heavier carbon dioxide gas than in air. Upon entering and leaving the CO_2 balloon, the sound waves experience refraction due to the change in medium. The waves are bent so as to converge at a single point behind the balloon, creating a focal point of high intensity. Waves are refracted away from regions behind the edges of the balloon, creating quiet areas with an absence of sound.

Teaching Notes:

- In order for students to better understand the refractive behavior of sound waves upon entering and leaving the CO_2 balloon, the teacher may wish to refer to *Demonstrations in Sound & Waves: Part I -Refraction of Waves in a Ripple Tank.* (One segment of the demonstration shows the refraction of water waves upon encountering a lens shaped shallow region.)

- The speed of sound in carbon dioxide is 259 m/s at 0 degrees Celsius.

- The teacher may wish to expound on the reflective behavior of sound waves which is observed for the sound source and parabolic reflector. In order for sound waves to be effectively reflected, the reflector must be of a size which is considerably larger than the wavelength. For this reason, sound waves having a frequency of 4000 Hz (8.5 cm wavelength) are used; a wavelength which is sufficiently short so as to be effectively reflected by the 40 centimeter parabolic dish. (If one could tolerate the high pitch, an even shorter wavelength would be ideal to work with.)

- Just as sound is refracted upon encountering a different gas, refraction also occurs when sound encounters a change in density within the same gas. This later case is commonly experienced on a calm lake at dusk when a cool (dense) layer of air is present over the water with a warmer (less dense) layer of air higher up. The sound is channeled due to upward traveling waves being refracted back down toward the surface, resulting in an increase in sound intensity for a listener across the lake.

Demonstration No. 5
Interference of Sound: Sound Divided into Two Paths of Differing Length
Length: 2:52 minutes / Location: 15:16 - 18:08 minutes

Objective: Trombone slide used to ↑ path length

To observe the interference of sound by splitting a single sound source into two paths of differing length, and then bringing the sound paths together again.

Using the Demonstration:
In order to observe the interference of sound, a speaker is mounted on a tube which splits the sound into two paths. The lengths of the two paths can be varied by a type of slide trombone arrangement. At the output end of the apparatus, the two sound paths are brought back together again and the sound emerges from a small horn. With the signal generator set at 3000 Hz, the wavelength of the sound emitted by the speaker is 11 centimeters.

When one of the slides is slowly pulled up so as to vary the length of one of the paths, the sound which emerges from the apparatus is heard to alternately increase and decrease in loudness. It is found that when the two path lengths are exactly equal, the sound intensity is at a maximum. If one of the slides is moved so as to increase its path length by 5.5 centimeters, a distance equal to a half-wavelength, the sound is heard to drop off to a minimum intensity. Lengthening the one slide by an additional half-wavelength causes the sound to become louder as it returns to its maximum level. This cycle is observed to continue whenever the length of one path is increased by a half-wavelength.

Having made these initial observations, the demonstration continues with a discussion of constructive and destructive interference. When the paths are of equal length, the sound travels the same number of wavelengths along either path, causing the two waves to arrive in phase at their meeting point. This results in constructive interference and the sound is heard to be relatively loud. When one of the slides is extended so that the two paths differ by a half-wavelength, the relative phase between the two waves becomes shifted and they arrive 180 degrees out of phase. With the crest of one wave overlapping the trough of the other, destructive interference occurs and the sound is heard to be very weak.

Whenever the paths differ by a whole number of wavelengths, the sound waves meet up in phase and constructive interference results. When the two sound paths differ by an odd number of half-wavelengths, destructive interference always results and the two waves cancel one another.

Teaching Notes:

- The importance of having the two sound paths originate from a single sound source should be discussed. The single sound source assures that waves along one path will keep a constant phase relationship (remain coherent) with waves along the other path.
- The slide trombone arrangement used in this demonstration to split a single sound source into two paths is analogous to an interferometer. An interferometer allows one to observe the interference of light by splitting a single light source into two paths of differing length and then bringing them back together again.
- By measuring the distance the slide moves in going from one maximum to another, this type of apparatus can be used to provide an accurate measurement of the wavelength of sound.

Demonstration No. 6
Interference of Sound: Beat Phenomena
Length: 3:50 minutes / Location: 18:23 - 22:13 minutes

Beats

Excellent

Objective:
To observe and examine the beat pattern produced by: 1) two tuning forks of slightly different frequencies, and 2) an electronic function generator producing two tones which differ slightly in frequency.

Using the Demonstration:
An interesting and important example of interference occurs in the phenomenon of beats. In order to demonstrate this type of interference, two tuning forks are used due to the fact they produce very pure tones and are therefore ideal sources of sound to work with. An adjustable pair of masses on one of the tuning forks allows its vibrational frequency to be slightly changed.

With the adjustable tuning fork set to vibrate at a frequency just slightly different from that of the other tuning fork, the two sources are set into vibration. The two sources do not act together to give a steady tone, but rather, a steady pulsating sound is heard. The oscilloscope display shows that the overall sound intensity alternately increases and decreases with time. This phenomenon is the result of interference between the sound waves from the two sources; the regularly spaced intensity changes are called beats. If the adjustable tuning fork is changed so that its frequency is made closer yet to that of the other tuning fork, the beat frequency produced by the two vibrating sources is observed to slow down.

The fact that interference is taking place is verified by striking the two tuning forks and then watching the oscilloscope as one of the forks is damped out. With one tuning fork vibrating, it is observed that sounding the second tuning fork actually causes the overall amplitude to be decreased. (This result takes place when a 180 degree phase difference between the two forks is captured upon a fortunately timed striking of the second fork.) When one of the forks is damped out, the overall amplitude increases. This clearly demonstrates that destructive interference is taking place.

By using an electronic function generator, two waves of perfectly equal amplitude can be sustained over time to give a better display of the beat pattern. With the two generated frequencies differing just slightly, the oscilloscope displays a well defined envelope that clearly shows the beat pattern. The oscilloscope's time scale is extended so that the rise and fall in amplitude is displayed at one given moment.

The demonstration closes with a detailed discussion of the formation of beats: To see how beats arise, consider two equal amplitude sound waves of slightly different frequency. What we actually hear is a resultant wave, formed by the superposition of the two original sound waves. At some point in time, the two waves are in phase and interfere constructively. The resultant amplitude is twice the amplitude of the individual component waves and we momentarily hear a louder sound. However, because the wavelengths differ slightly, a short time later the two waves are no longer in phase and the resultant amplitude starts to decrease. Eventually, the two waves become completely out of phase and perfect destructive interference occurs. The resultant amplitude goes to zero and the sound is momentarily canceled out. Thereafter, the cycle repeats itself, creating an interference pattern which changes with time.

Teaching Notes:

- Listening to the beat pattern, we hear a sound whose frequency is the average of the two sources and whose intensity oscillates at the frequency $f_1 - f_2$ (beat frequency).
- The maxima and minima sound intensity for a two speaker interference system vary with position at a given time. The opposite is true for beats, the maximum and minimum vary with time at a given position. (Beats are a function of time, not position.)
- The human ear can detect up to about seven beats per second; at higher beat frequencies the beat pattern becomes indiscernible.
- The phenomenon of beats can occur with any kind of wave and is a very sensitive method for comparing frequencies. To tune a piano or guitar, the tuner listens for beats produced between a standard tuning fork (or another tuned string) and that of a string which is to be tuned. The string is perfectly tuned when the beats are no longer present. The phenomenon of beats also makes it possible to determine frequencies very accurately if we know one frequency and measure the beat frequency.

Demonstration No. 7
Diffraction of Sound: Bending of Sound by an Obstacle
Length: 2:45 minutes / Location: 22:30 - 25:15 minutes

Objective:
To observe the diffraction of sound upon encountering a circular obstacle.

Using the Demonstration:
It is a characteristic property of waves that they will bend around the edges of obstacles placed in their path and enter into the "shadow" region behind the obstacle. In order to observe diffraction of sound waves, a sound source is used which consists of a speaker positioned at the focal point of a parabolic reflecting surface. With the signal generator set at a frequency of 4500 Hz, the short wavelength sound is reflected into a parallel beam. (See Demonstration No. 4 for a description of the sound source and reflector.) A solid circular disk is used as an obstacle and is inserted into the sound path. A microphone connected to an oscilloscope serves to examine the sound intensity at various points behind the obstacle.

Upon moving the microphone into the shadow region behind the obstacle, it is found that the sound intensity does not drop sharply behind the edge of the obstacle, but instead, drops of gradually before going to zero. Moving in farther behind the disk, it is found that the sound intensity actually increases before dropping back down to zero. Clearly, sound waves are somehow managing to bend around the edge of the disk in order to be present at such locations.

If the microphone is moved directly behind the center of the disk, the sound intensity is surprisingly found to be at a maximum. This well defined "loud spot" is found in the center of the shadow region where one would expect the sound waves to be totally blocked off from the source. In summary, intense areas of sound are found behind the edges and center of the disk.

These observations convincingly show that sound experiences the wave behavior of diffraction. When sound is incident on the circular obstacle, the waves are diffracted so as to bend around the edges. The diffracted waves all converge on a central point behind the disk. These waves are in phase and therefore interfere constructively, forming a central loud spot of maximum sound intensity.

Teaching Notes:
- It was found that with the 25 cm diameter circular disk, sound waves of frequency 4500 Hz (7.6 cm wavelength) produced defined and distinct edge fringes. At lower frequencies, it was found that edge fringes were hard to detect and not as distinct.

- In order for students to better understand the diffraction of sound waves around an obstacle, the teacher may wish to refer to *Demonstrations in Sound & Waves: Part I - Diffraction of Waves in a Ripple Tank.*

- It should be pointed out that in the shadow region behind the obstacle constructive and destructive interference is taking place causing the diffracted waves to experience maxima and minima. (Note that the diffraction animation only shows the central maximum and does not show edge fringes for the sake of clarity.)

- Diffraction plays an important role in the propagation of sound. We can listen and talk to a person standing out of our line of sight (around the corner of a building for example) because the sound waves diffract around the corner.

Demonstration No. 8
Doppler Effect: Frequency Shift of Moving Sound Source
Length: 1:58 minutes / Location: 25:30 - 27:28 minutes

Objective:
To observe the Doppler effect for sound waves by using a rapidly rotating sound source.

Using the Demonstration:
If sound is emitted by a moving source, the wavelength of the sound wave is changed. To demonstrate this, a musical reed is used as a sound source and is mounted on the end of an arm attached to a rotator. With the reed motionless, forcing compressed air through it produces a steady, high pitched sound.

The reed is then put into motion as it is rotated rapidly in a circle at a constant angular velocity. The sound emitted by the reed is no longer heard to be at a constant frequency; but alternately rises and falls in pitch as the reed approaches and recedes from the stationary microphone. This change in perceived frequency due to the relative motion between the source and the receiver is called the Doppler effect. If the reed is rotated at a higher rate so that it approaches and recedes from the microphone with a greater velocity, the change in frequency is also heard to be greater.

An animation is used to illustrate how sound waves are affected by a moving source: As the reed moves, it is continually catching up with the previously emitted wavefronts. Thus, the sound waves emitted in the forward direction are closer together than normal. The observer detects more wave crests passing per second, so the perceived frequency is higher than when the source is at rest. The wavefronts which are emitted behind the moving source are farther apart than normal because the source is always moving away from them. Therefore, fewer wave crests per second pass by an observer positioned behind the source and the pitch becomes lower.

Teaching Notes:

- In a lab setting, a rapidly rotating (or oscillating) sound source provides the only way to observe the Doppler effect. In this case, the quickly rising and falling pitch gives a fluttering effect in contrast to a passing train or automobile which produces a single distinct frequency shift.
- The Doppler effect occurs not only for sound, but for all types of waves. Light exhibits the Doppler effect, and applied to astronomy, allows us to determine the velocities of distant galaxies. Light from distant galaxies is shifted toward lower frequencies, this "red shift" indicates that the galaxies are moving away from us.
- The Doppler effect can be nicely shown for water waves in a ripple tank by moving a periodic source across the surface of the water at a constant rate.