PHYSICS DEMONSTRATIONS IN SOUND & WAVES

PART I

Demonstration No. 1

Mechanical Resonance: Forced Vibrations with Single and Coupled Oscillators

Length: 4:22 minutes / Location: 00:45 - 05:07 minutes

Objective:

To study the phenomenon of resonance in a mechanical oscillator. The behavior of a single oscillator is observed as the frequency of an external driver is varied, from values ranging below, to those ranging above the oscillator's natural frequency. In addition, resonance is observed in systems composed of two and three oscillators coupled together.

Using the Demonstration:

Virtually all things vibrate or oscillate at a characteristic frequency. In order to demonstrate how a vibrating object responds to an outside driving force, an air-track glider and a variable frequency driver are used. Springs are attached to either side of the glider, with one spring leading to a rigid support and the other spring directly coupling the glider to the driver arm.

Initially, the glider is displaced from its rest position and allowed to oscillate at its characteristic frequency. With no external driving force acting, the natural frequency of vibration is observed. Next, the external driving force is applied. With the driving frequency initially set at a value much lower than the glider's natural frequency, the glider at first goes through a transient stage, wanting to vibrate at its own natural rate and resisting the driving force. However, it ultimately gives way and reluctantly vibrates at the frequency imposed upon it by the external force. Although the glider succumbs to the external force, the amplitude of its oscillations remain small.

Resonance

When the driving frequency is increased, the glider becomes more responsive as its vibrations start to grow. At this point it is observed that the glider moves in step, or in phase, with the driving arm. When the driving frequency is increased to a point where it just matches the natural frequency of the glider, the amplitude of oscillation becomes exceptionally large. The powerful effects of resonance are clearly seen. At resonance, there is maximum energy transfer from the driving source to the oscillator, and a relatively small force can be used to obtain a large amplitude vibration. It's important to note that at resonance the motion of the driving arm is not perfectly in phase with the motion of the oscillator; instead, the driving force leads the oscillator by a fraction of a cycle.

Increasing the driving frequency to a value slightly above the resonant frequency causes the amplitude of vibration to once again diminish. The driver arm and glider are observed to be completely out of phase as the two motions oppose one another at all times. At frequencies significantly above the resonance frequency, the glider shows virtually no response to the driving force.

A system composed of a single oscillator has only one resonant frequency and one characteristic mode of vibration. However, when two gliders are coupled together, two resonant modes of vibration are observed. At one resonant frequency, the two gliders move in unison. At a 2nd higher resonant frequency, the two gliders move so as to oppose each other. When three gliders are coupled together, three different resonant modes of vibration come into being. In general, the number of independent modes of vibration will always equal the number of oscillators present in the system.

Teaching Notes:

- It should be emphasized that the amplitude of the driver remains constant throughout the demonstration, only the frequency is varied.
- This demonstration may be used as an introduction to standing waves which are also an example of

resonance. Just as the oscillator being driven at an appropriate frequency results in large amplitude vibrations, so the same is true for transverse and longitudinal waves. (As a matter of fact, it is very interesting to note that when the 2-body or 3-body systems are in resonance, the oscillators are simply moving in the same way as particles within a medium supporting a standing longitudinal wave.)

- At the close of the demonstration it is observed that as the number of oscillators increases, the number of resonant vibrational modes also increases. (For one-dimensional motion, a system of N masses has exactly N independent modes of vibration.) A case can be built that a continuous system (such as a rope or spring) has an infinite number of small individual oscillators and, therefore, ideally has an infinite number of resonant modes and accompanying resonant frequencies.
- In performing the demonstration with two coupled gliders, one actually finds that three different vibrational patterns can be found. The third vibrational pattern, in which one glider remains stationary while the other oscillates, is not a normal mode of vibration. This third mode does not maintain a consistent vibrational pattern over time, but instead, changes over time as energy is transferred between the two gliders. The normal modes of vibration are only those modes which do not change with time. Similarly, the system of three coupled gliders has more than three patterns of vibration, however, only three of these remain constant with time.

1st half - good intro to transverse wave

Demonstration No. 2
Velocity/Wavelength & Frequency/Reflected Waves: Transverse Waves on a Coil Spring
Length: 3:20 minutes / Location: 05:22 - 08:42 minutes

2nd half is reflection

Reflection

Objective:
By generating transverse waves on a coil spring, the following fundamental wave properties will be observed: factors determining wave velocity; relationship between wavelength and frequency; and reflection from a fixed and free end.

Using the Demonstration:
For the study of wave behavior, a coil spring has long been used in introductory physics classes to very nicely demonstrate wave properties. The coil spring provides what perhaps may be one of the clearest, and most directly observable means of studying one-dimensional wave behavior. Although the apparatus is common and readily available to physics instructors, it is included in this collection of video demonstrations so that the instructor may have a convenient visual tool which concisely summarizes (or reviews) fundamental wave properties. In addition, the video enhancements of slow-motion and superimposed graphics allow for improved observation.

amplitude

wave vel.

The demonstration initially discusses the nature of a transverse wave. It should be reinforced that waves in general can travel over large distances, however, the medium itself merely oscillates about an equilibrium point and no matter is transported by the wave. Next, it is observed that wave amplitude has no effect on the wave velocity, as pulses of both small and large displacement are seen to travel with identical velocities. When the spring is stretched, and the tension within it increased, the properties of the medium are made to be somewhat different. The wave velocity is observed to be greater in the stretched spring. By stretching the spring, we have in a sense created a different medium, and have brought into play the single most important factor which determines the speed of a wave.

With a continuous back and forth disturbance, a continuous transverse wave is created on the spring. The frequency of the wave is the same as the frequency at which the spring is shaken. At a given frequency, the waves are observed to have a definite wavelength. As the frequency is increased, the wavelength is observed to become shorter. It should become apparent to students that an inverse relationship exists between frequency and wavelength.

If the end of the spring is held fixed, a wave which is sent down the spring undergoes reflection at the fixed end. It is observed that the reflected pulse is inverted relative to the incident pulse. This is explained by looking at the dynamics of the reflection process. While the reflection is taking place, the incident wave exerts an upward force on the support, in response, the support exerts a downward reaction force on the spring. The net result is that an inverted wave of the same form is reflected back along the spring.

Finally, a long segment of light string is attached to the end of the spring so that it is no longer constrained in its motion and allowed to move freely. A wave pulse sent down the spring is again observed to be reflected from the lose end. This time, however, the reflected pulse is not inverted, but rather returns on the same side of the spring as the incident pulse. It should be noted that the momentary displacement at the free end is larger than the actual wave displacement. For a brief moment during the reflection, portions of the reflected wave and the incident wave are present simultaneously, and add together to produce a displacement which is larger than that of the incident (or reflected) pulse.

Teaching Notes:

- This demonstration can be put to good use after students complete a lab involving waves on a coil spring. The video demonstration can be used to reinforce student observations in a post-lab discussion.

- The fact that wave behaviors observed on a coil spring apply to all types of waves cannot be emphasized enough to students. When studying other types of wave phenomena in which the waves themselves cannot be directly observed, as is the case for sound and light, a fundamental understanding can be achieved by calling to mind and relating the behavior to that of waves on a coil spring.

- It is important to note that although observations were made for transverse waves on a coil spring, these same behaviors also hold true for longitudinal waves. The one exception is the phase of a reflected wave from a rigid boundary. Although transverse waves undergo a 180 degree phase change upon reflection from a rigid boundary, longitudinal waves do not. Contrary to what is stated in many introductory physics texts, longitudinal waves experience no phase change upon reflection from a rigid boundary, and the incident and reflected waves are in fact in phase with each other.

- In order to produce a continuous traveling wave on a coil spring, with no interference effects or standing wave effects from the non-driven end, all reflections must be damped out. By using a light blanket loosely draped over the final two meters of the spring's length, the oncoming waves do not strike any harsh discontinuity which would cause reflection to take place. Instead, the waves are gradually damped out over the final two meters, and a clean continuous wave is produced over the rest of the spring.

Superposition, interference

Demonstration No. 3
Change in Medium/Interference: Transverse Waves on a Coil Spring
Length: 4:29 minutes / Location: 08:57 - 13:26 minutes

Objective:
By generating transverse waves on a coil spring, the following fundamental wave properties will be observed: constructive interference; destructive interference; wave behavior at the boundary of a different medium.

Using the Demonstration:
This demonstration is a follow-up to the preceding demonstration, and completes a two-part study of one-dimensional waves on a coil spring. Initially, the demonstration examines interference between two waves on a coil spring. Two pulses of the same amplitude, both having upward displacements, are produced at opposite ends of the spring. Seen in real time, the two pulses pass through one another unchanged after meeting in the center. In order to see what is happening during the short time when the two waves overlap, slow motion is used. When the waves partially overlap, slow motion reveals that a new complex looking waveform is momentarily created. As the waves move so as to completely overlap, the newly created wave is observed to have a displacement which is greater than that of either individual pulse as constructive interference takes place. In accordance with the principle of superposition, the total displacement of the spring at any instant is equal to the sum of the displacements of the two pulses independently. After the interference takes place, it's important to note that the two pulses assume their original shapes and continue their propagation along the spring.

Next, two waves of equal amplitude but opposite displacement are produced. Once again, it is observed that the waves pass through one another unchanged. However, as the waves overlap, slow motion reveals there is clearly a moment when the entire spring appears undisplaced as the two waves completely cancel each other. The students see a good example of total destructive interference as the positive upward pulse adds to the negative downward pulse to produce a zero displacement. Although the wave is momentarily destroyed, the energy of the disturbance is not. The energy is still very much present and can be shown to be stored in the spring. After the interaction, it is seen that the wave cancellation is only temporary as the two pulses reappear on the spring, showing no sign that destructive interference ever took place.

A third interference event is created by having an upward pulse of relatively small amplitude encounter a downward pulse of larger amplitude. Here, the teacher may wish to pause the video and have students predict the outcome based on the superposition principle. As expected, the two pulses interfere destructively, although total destructive interference does not take place. The displacement of the small upward pulse subtracts from that of the larger downward pulse, giving a net result of a small downward displacement.

To demonstrate the behavior of waves at the boundary of a different medium, a relatively heavy spring is coupled together with a lighter spring. A pulse generated in the heavier medium is observed to speed up upon entering the lighter medium. In addition, when the pulse reaches the boundary, part of it is reflected and part is transmitted. For the situation of traveling into a lighter medium, the reflected pulse is non-inverted. When a continuous wave is generated in the heavier spring, it is seen that the wavelength becomes substantially longer upon entering the lighter spring. It should also be noted that there is no change in frequency at the boundary, simply because the two springs are directly coupled together and therefore must both move up and down together at the same rate.

Teaching Notes:

- In the portion of the demonstration dealing with interference, only two waves are present on the coil spring. However, it should be pointed out that the superposition principle applies no matter how many separate waves are present in the medium. Each wave makes its own contribution, with the net result simply being the sum of all the individual contributions.

- In the third interference event the two pulses have different amplitudes, thus allowing one to track each pulse before and after the interaction. By tracking either the large amplitude pulse or the small amplitude pulse, it can be verified that the waves do in fact pass through each other, and are not somehow reflecting off one another.
- At this early point in the study of waves, the teacher may wish to have students start thinking of how wave properties observed on the coil spring would be physically observed in other types of waves. (e.g. What would you expect to observe for the case of total destructive interference occurring in water, sound, or light waves?)

Standing Waves

Demonstration No. 4

Transverse Standing Waves: Vibrational Modes on a String

Length: 5:12 minutes / Location: 13:40 - 18:52 minutes

Objective:
The objective of this demonstration is three-fold: (1) to illustrate the construction of a standing wave from two component traveling waves using computer animation and the superposition principle. (2) to observe the characteristics of a standing wave on a vibrating string. (3) to examine the hidden features of a standing wave by utilizing stroboscopic illumination.

Using the Demonstration:
A thorough understanding of standing waves is extremely important if students are to grasp such concepts as acoustical resonance, modes of vibration, and quality of sound. In acoustical applications, standing waves are not directly observable. By examining transverse standing waves on a string, standing wave phenomena can be studied in a straight forward manner.

By using a jigsaw to drive the end of a string up and down with a regular periodic motion, continuous waves are produced on the string. A hanging mass and pulley at the end of the string provide a fixed end, while also keeping the tension constant. With the generated wave being constantly reflected from the fixed end, there always exists two identical waves on the string traveling in opposite directions.

Before the result of two oppositely directed waves is actually observed, computer animation is used to draw the waveform predicted by the superposition principle. The animation presents two component traveling waves of the same velocity, amplitude, and wavelength, traveling in opposite directions. The result of applying the superposition principle is seen as the amplitudes of the two component waves are added together. With each of the component waves moved through successive quarter cycle intervals, the resultant wave is seen to go through alternate periods of constructive and destructive interference. When the component waves move continuously, it is observed that the resultant wave does not appear to travel at all, but instead, there are fixed points where complete destructive interference occurs at all times. Additionally, the points of maximum displacement are seen to oscillate back and forth at certain fixed points along the wave.

When the driver is first turned on, the string is seen to vibrate with small chaotic displacements as the generated waves and reflected waves interfere in a randomly shifting manner. However, when the frequency of the driver is slowly increased, a frequency is found which causes the string to undergo a large displacement. At this point no traveling wave can be discerned. What is observed is a standing wave vibrating at its fundamental frequency. This first mode of vibration has a single antinode which exists at the very center of the string, with nodes located at each end. It should be noted that the string takes on a half-wavelength pattern between the fixed ends.

Increasing the driving frequency causes the first vibrational mode to disappear. At precisely twice the fundamental frequency, a second well-defined pattern is formed. This time, the standing wave has a stationary nodal point at the center with antinodes on either side. The oscillating string vibrates so rapidly that the eye perceives only a blur, whose shape is that of the envelope of the motion.

By illuminating the string with a strobe, a slow motion effect is created to better observe the string's motion. The stroboscopic illumination allows one to see that the string is always vibrating in opposite directions on either side of a node. (This important observation is critical to understanding longitudinal standing waves.) At the 2nd standing wave pattern which is characterized by a central node, the string vibrates such that one full wavelength precisely fits between the fixed ends. It's interesting to note that the frozen strobe image of the standing wave provides a good picture of the component traveling waves, the only difference being that it has a maximum amplitude which is twice that of either component wave.

When the driving frequency is increased to 3 times the fundamental, a standing wave is produced which has four nodes and three antinodes. At this frequency, the string vibrates such that 1.5 wavelengths fit along the string. It is found that a new standing wave is produced every time the frequency is increased to some whole number multiple of the fundamental frequency, with an extra half-wavelength always being introduced along the string.

Teaching Notes:

- It is important for students to recognize that although a standing wave is the result of interference between two identical waves traveling in opposite directions, it should also be understood as a vibrating object which is at resonance.

- Resonant behavior can be seen in the standing wave by noting that the driver oscillates with a relatively small amplitude, whereas the amplitude of the standing wave antinode is significantly greater. (This is particularly true for the fundamental frequency.)

- The boundary condition of a node at each end of the string requires that only multiples of half-wavelengths fit along the string. (Although the end of the string which is attached to the driver moves slightly, it does approximate a node due to the fact that the amplitude of the driver is small compared to that of the string.)

- Standing waves are produced not only on strings, but on virtually any object that is set into vibration. When a bell, a piece of wood, or a drinking glass is struck, standing waves are set up that correspond to the natural resonant frequencies of that object. All musical instruments depend on standing waves to produce their musical sounds, from string instruments, to wind instruments, to percussion instruments.

Good intro-to long. waves - 1st half

2nd half shows interference

Demonstration No. 5
Longitudinal Waves: Propagation/Interference of Longitudinal Waves
Length: 3:45 minutes / Location: 19:08 - 22:53 minutes

Objective:
To examine the way in which a longitudinal wave propagates through a medium; to draw a comparison between longitudinal waves and transverse waves; and to observe constructive and destructive interference in longitudinal waves.

Using the Demonstration:
Although most students have a pretty good understanding of transverse waves and the way in which they propagate through a medium, many do not have a good picture of the mechanism by which longitudinal waves propagate. In particular, the motion of the medium as a longitudinal wave travels through is difficult to envision from static illustrations.

In this demonstration, longitudinal waves are produced on a long helical spring which is suspended horizontally by a number of light strings. When the end of the spring is sharply displaced back and forth in the direction of the spring's length, a longitudinal pulse is seen to propagates down the spring. With the aid of slow motion, it is seen that the leading edge of the pulse compresses the medium, whereas the trailing edge of the pulse creates an expansion in the medium. By analogy with a transverse wave, the area of greatest compression corresponds to a crest, whereas the area of greatest expansion corresponds to a trough.

In order to carefully focus on one element of the medium and observe its motion, a circular marker is attached to one of the coils. As the leading edge of the longitudinal wave approaches, the marked coil becomes displaced to one side of its equilibrium position, parallel to the direction of the wave motion. The coil then moves to the other side of its equilibrium position as the trailing edge of the wave goes by. Finally, the coil returns to its equilibrium position after the wave passes. For every individual coil in the medium, this same oscillation pattern takes place in succession. This type of oscillatory motion among the particles of the medium is the very essence of a longitudinal wave. An animation of a compressional pulse initiated in a series of rods is used to give a clear picture of the motion of successive elements in the medium.

Two pulses produced on opposite ends of the spring, and traveling in opposite directions, are observed to pass through one another unchanged. Both pulses travel with a compression leading the way and an expansion following behind. When the two waves first meet, constructive interference can be observed as the compression amplitude grows significantly. (evidenced by a large group of tightly compressed coils.) As the waves continue to move through each other, destructive interference momentarily occurs as the compressions overlap with the expansions. Finally, constructive interference occurs for a second time as the expansions superimpose, producing a significantly larger expansion in the spring. After the interaction, the two pulses assume their original shapes and continue their propagation along the spring.

Teaching Notes:

- It should be emphasized that although the longitudinal wave itself can travel over a large distance, each element of the medium merely oscillates over a very small distance. No matter is carried along with the wave.

- It is helpful to discuss the way in which constructive and destructive interference is physically observed in longitudinal waves as opposed to transverse waves.

- Both longitudinal and transverse waves can travel through a solid since the atoms or molecules can vibrate about their fixed positions in any direction. However, in a fluid, only longitudinal waves can propagate due to the fact that any transverse motion would experience no restoring force since a fluid can flow.

Demonstration No. 6

Longitudinal Standing Waves: Stroboscopic Analysis of Standing Wave Behavior

Length: 5:20 minutes / Location: 23:12 - 28:32 minutes

Objective:
To analyze the characteristics of a longitudinal standing wave. A longitudinal standing wave established on a spring will be examined in detail with the aid of stroboscopic illumination.

Using the Demonstration:
Standing longitudinal waves are among the more difficult behaviors to visualize in all of introductory physics. When representing longitudinal standing waves, text books often show transverse standing waves for the sake of simplicity. In light of this, students may have a good working picture of a transverse standing wave, but not necessarily of a longitudinal standing wave. For longitudinal waves, the compressing and expanding motion of the medium gives rise to a standing wave with some unique characteristics. It is the intent of this demonstration to carefully observe a standing longitudinal wave, and in so doing, gain a full working understanding of it.

Continuous longitudinal waves are produced on a vertically suspended spring by means of a variable-frequency mechanical driver. With the generated waves being constantly reflected from the fixed end, there always exists two identical waves on the spring traveling in opposite directions. At a particular frequency, a standing wave pattern is formed due to interference between the generated waves and reflected waves. However, the precise way in which the individual coils move is not at all clear, as the spring oscillates so rapidly that the eye perceives only a blurred pattern.

By using stroboscopic illumination to give a slow motion effect, it is possible to closely examine the properties of a longitudinal standing wave. At first glance, students might be tempted to conclude that a displacement antinode exists at the point where the coils are alternately being compressed and expanded. However, a closer look reveals that the single coil in the center of the compression and expansion is not moving at all, as this is in fact the location of a displacement node. (Seen under normal lighting, the displacement nodes occur at the center of the pulsating dark regions along the spring.) Midway between two nodes, a point can be found where the spring coils are vibrating back and forth with a maximum displacement; this point is an antinode. On a longitudinal standing wave, the antinode is not as apparent as on a transverse standing wave due to the fact that we can't just focus on one point on the medium, but rather, must focus at one fixed location along the wave.

As with a transverse standing wave, the distance from node to node represents a half-wavelength, with one full wavelength composed of two such intervals. A frozen image taken at a displacement extreme provides a good picture of the component traveling waves which exist on the spring, the one difference being the amplitude of the individual traveling waves is half that of the frozen image.

If we use the spring to represent a standing sound wave in air, then the coils themselves represent air molecules. Areas on the wave where the coils go from being tightly compressed to greatly expanded correspond to what would be a strong fluctuation in air pressure. It's surprising to find that points where the air molecules are not moving at all, the displacement nodes, are exactly where the pressure variation is greatest, the pressure antinodes. We can understand this by observing the coils, or air molecules, vibrating in opposite directions on either side of the displacement node. When the coils approach each other the pressure at the node is increasing. When they recede from each other, the pressure at the node is decreasing. This same unexpected behavior holds true for the displacement antinode, where we oddly enough find a pressure node. Here, air molecules which are on opposite sides of the displacement antinode vibrate in unison, and therefore no compression or expansion occurs as the pressure remains constant at this point.

Initially, diffraction is observed by placing a small barrier in the path of the water waves so that it intercepts part of the wave front. As the waves pass the edge of the barrier it is observed that they do not continue on their straight path, but are bent so as to travel directly behind the obstacle (into what might be called the "shadow" region). It is seen that when the wavelength and obstacle are close in size, the waves are bent strongly. If the wavelength is made shorter, diffraction takes place to a lesser degree. With the wavelength significantly smaller than the obstacle, the bending is considerably less as the shadow becomes sharper.

Next, straight waves are made to be incident on a slit-like opening created between two barriers. After passing through the slit, diffraction is again observed as the waves bend around the edges of the slit to form an expanding wave front which is wider than the actual slit width (a narrow and defined beam is not formed). With the wavelength kept constant, it is observed that decreasing the slit width causes the waves to experience a greater degree of bending. If the slit width is decreased such that it is much smaller than the wavelength, the waves become so strongly diffracted that they spread out in all directions and take on a circular wave front.

By using two point sources which generate identical periodic waves, interference is observed. As the circular waves travel outward, they overlap and interfere with one another, forming a pattern of nodal and antinodal lines that radiate outward from the two sources. With the two sources vibrating in phase, the line which runs down the center of the pattern is observed to be an antinodal line and is made up of large amplitude waves. Due to the fact that all points along the central line have equal path lengths from the two sources, the waves arrive in phase and constructive interference results. Antinodal lines on either side of the central line occur when the path difference is 1, 2, 3,... full wavelengths. Bordering the central line is a nodal line in which no waves are observed to exist as the water is virtually undisturbed. The path lengths from each source to any point along this line differ by a half-wavelength. Waves therefore arrive a half-cycle out of phase and destructive interference results. Nodal lines occur whenever the path difference is an odd number of half wavelengths.

In order to lay the groundwork for double-slit interference of light, a barrier with two narrow slits is placed in the path of plane waves. It is interesting to note that an interference pattern is formed which is identical to that created by two point sources. Due to diffraction, the double slits act as point sources, producing coherent waves which overlap and experience constructive and destructive interference.

Finally, a straight barrier is placed across the center of the tank parallel to the advancing waves. A standing wave is formed as a result of the superposition of the advancing waves and the waves reflected from the barrier. Stationary nodal and antinodal lines are observed as the reflected waves are at some points reinforcing the oncoming waves, while at other points there is always cancellation.

Teaching Notes:

- The single-slit diffraction pattern can be observed to consist of a central maximum along with weaker secondary maxima on either side. It may be wise to focus attention on the central maximum, and avoid a discussion on the detailed structure of a single-slit diffraction pattern at this time.

- The phase relationship between two sources producing an interference pattern is of great significance. For the case of the interference pattern produced in the ripple tank, the phase relationship between the two point sources remains constant due to the fact that both agitators are directly linked to the same motor. If the phase relationship between the two sources was continually changing, the interference pattern would be continually shifting and well-defined nodal and antinodal lines would not be observed. (A constant phase relationship between two sources becomes particularly important when dealing with interference of light.)

as the source is in front of it. This corresponds to the situation in optics where a ray of light reflected from a mirror appears to come from the image point behind the mirror.

Next, a barrier in the shape of a parabola is placed in the path of plane waves. The reflected waves are observed to converge at the focal point of the curved reflector. Similarly, circular waves produced at the focus of the parabolic reflector produce parallel plane waves upon reflection, and the wave paths are simply reversed. In both cases the law of reflection is obeyed, as the angle of incidence equals the angle of reflection for all points along the reflector's surface.

By placing a thick glass plate in the bottom of the tank, a region of shallow water is created in which the wave velocity is slower. The two different depths of water therefore constitute two different media in which waves can propagate. Waves originating in the deeper water are observed to change direction upon entering the shallow region as the waves experience refraction. In addition, the wavelength is observed to become shorter as the waves pass across the boundary. By graphically drawing a line which is normal to the boundary between the deep and shallow water, the angle of incidence and the angle of refraction is measured. For the case of waves passing from a faster medium into one in which their velocity is slower, it is seen that the angle of incidence is greater than the angle of refraction as the waves bend toward the normal.

Finally, a shallow region is created in the shape of a convex lens. It is observed that the oncoming straight wave fronts are refracted in such a way as to converge to a focus in the deep region beyond the lens. The water waves give a nice display of the focusing property of a convex lens, allowing one to see just how a wavefront looks after passing through such a refractive device.

Teaching Notes:

- It can be quickly discerned that the wave velocity decreases upon entering shallower water simply by observing the decrease in wavelength. Because the frequency does not change upon entering the shallower water, the wave equation, $v = f\lambda$, reveals that a decrease in wavelength must be accompanied by a decrease in velocity.

- As an incident wave strikes the boundary between deep and shallow water, a weak reflected wave can be observed in addition to the refracted (transmitted) wave.

- Due to refraction, water waves in a lake always seem to approach the shore parallel to the shoreline even though they might be traveling almost perpendicular to the shore while in deep water. As the waves approach shallow water near the shore, the decrease in wave velocity causes the wavefront to refract inward toward the shoreline.

Demonstration No. 8

Waves in Two-Dimensions: Interference and Diffraction of Waves in a Ripple Tank

Length: 4:46 minutes / Location: 32:42 - 37:28 minutes

Objective:

To examine diffraction and interference of water waves in a ripple tank.

Using the Demonstration:

Because many types of waves cannot be directly seen, easily observed water waves provide a truly extraordinary look at the behavior of waves – behaviors which are characteristic not only of water waves, but of waves in general.

Just as with transverse standing waves, the lowest frequency at which a longitudinal standing wave is found to exist, the fundamental frequency, has an antinode at the center of the spring with nodes at each end. At twice the fundamental frequency, the second standing wave pattern takes shape with a node in the center of the spring and antinodes on either side. This progression continues, with an extra node and antinode being added each time the frequency is increased to the next whole number multiple of the fundamental frequency.

Teaching Notes:

- When teaching a unit on sound, a better grasp of standing sound waves can be achieved by making the correlation to longitudinal standing waves on a spring. This correlation quickly makes obvious an area of confusion: the difference between the displacement amplitude and the pressure amplitude; and why they do not occur at the same point on the wave, but instead, are 90 degrees out of phase.
- For a transverse standing wave, the antinode takes place at one stationary location along the wave and also at one particular point on the medium. For a longitudinal standing wave this is not true. The antinode takes place at one stationary location along the wave, but not at one particular point on the medium. As seen in the demonstration, a number of coils are observed moving back and forth past the antinode position as the maximum displacement takes place on different coils at different times.
- It should be emphasized that the different standing wave patterns are in fact different resonant modes of vibration. Having observed longitudinal standing waves on a spring, students should have a good picture of acoustical resonance in air-columns and the associated motion of air molecules.

Somewhat. useful

Demonstration No. 7

Waves in Two-Dimensions: Reflection and Refraction of Waves in a Ripple Tank

Length: 3:32 minutes / Location: 28:51 - 32:23 minutes

Objective:
To examine the reflective and refractive properties of water waves in a ripple tank.

Using the Demonstration:
In order to extend the study of waves to two-dimensions, waves are generated on the surface of water using a ripple tank. By shining a point source of light through the tank and onto a screen, the crests and troughs on the water surface are observed to show up as bright and dark bands. (The crests of the waves act as converging lenses and focus the light, forming bright bands. The troughs act as diverging lenses and spread the light out, forming dark bands.)

Initially, a straight barrier is positioned diagonally in the tank. An incident wave is observed to bounce off the barrier and travel in a different direction. This process is that of reflection. Rays which are drawn perpendicular to the wave fronts show the direction of propagation of the incident and reflected waves. With the incident and reflected angles measured relative to a line drawn normal to the reflecting surface, it is seen that the angle of incidence equals the angle of reflection. This law of reflection holds not only for surface waves on water, but for all types of waves as well.

For the case of an expanding circular pulse incident on a straight barrier, the curvature of the reflected wave is observed to be a continuation of the incident wave as only the direction of propagation is changed. It is important to note that the reflected pulse can be viewed as originating at the same distance behind the barrier