S10a: Mechanical Waves

Introduction:

Waves lapping up on the beautiful beach shore, the ripples in a pond, the sound of a physics instructor's voice, and even the music that emerges from the radio; all of these phenomena have one major thing in common: waves. A wave is a disturbance in a medium, through which the disturbance can travel, or propagate, from one area in the medium to another. This commonly accepted definition is by no means a concrete standard, and due to the complexity of what a wave is and how it behaves, Wave Theory in physics is one of the more complex branches of study.

In an effort to provide familiarity with waves and their behavior, this experiment is designed to examine the nature of two different kinds of mechanical waves: transverse and longitudinal. Transverse waves will be explored using an oscillating string. The relationship between wave speed, wavelength and frequency will be examined together with how linear density and string tension affect these parameters. Careful adjustment of these parameters will demonstrate resonance in the string oscillations, usually referred to as standing waves. Longitudinal waves will be explored using sound waves. A speaker placed at the end of a long glass tube produces longitudinal sound waves in the air enclosed by the tube. Resonance occurs when the frequency of the sound matches the natural resonance frequency of the tube. By varying the frequency and covering one end of the tube, different conditions for resonance can be created. With the collected data the relationships between tube length, type, wavelength, frequency and sound speed can be examined.

Apparatus:

- Mechanical Wave Driver
- Pulley, Clamps, Mounting Hardware and Strings
- Mass Set with Hangers
- Precision Mass Scale
- Meter Stick
- 1 Meter Glass Tube with Rubber Stopper
- Speaker 100Hz to 20kHz Response Range
- Sound Sensor
- Hook-Up Wires
- Computer with Interface and Software

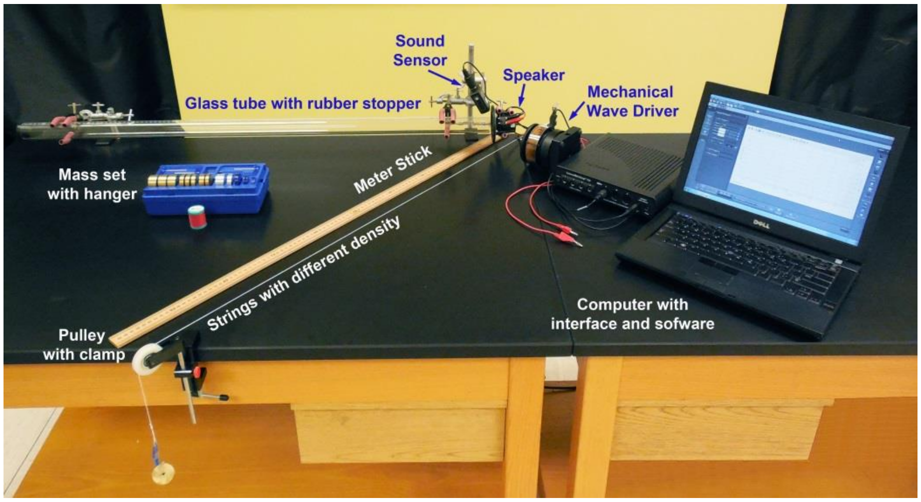

Figure 1

Discussion:

Rather than try to establish a universal definition for what it means to be characterized as a wave, first we will focus on the behavior of waves as they travel down an oscillating string, also known as a transverse wave. In a transverse wave, the displacement of the medium (in this case the displacement of the string) is perpendicular, or *transverse*, to the direction of travel of the wave. The form of a wave can be represented graphically as either a sine or cosine function, or even a sum of both. The amplitude of a wave is the maximum displacement of a particle from the equilibrium position. The wavelength λ, is the distance between successive corresponding points on a wave at a particular moment of time, e.g., between successive crests or valleys. Consider the representation offered in **Figure 2**.

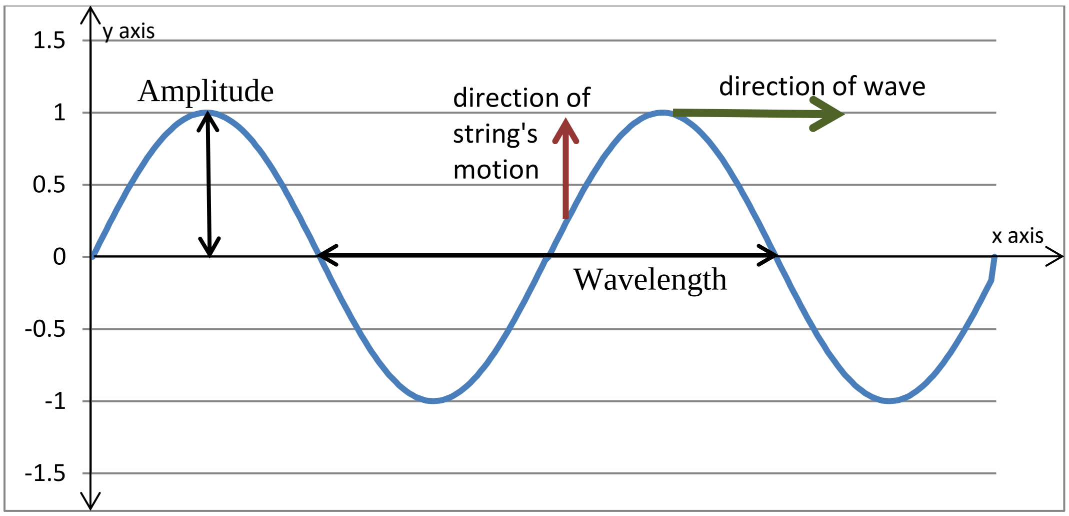

Figure 2

The frequency *f*, of a wave is the number of pulses generated per unit time, and is usually expressed in vibrations per second or cycles per second. The period *T*, is the time required for one complete oscillation which is also the time required for the wave to travel through one complete wavelength. The frequency is the reciprocal of the period as in equation (1),

$$f = \frac{1}{T} \qquad (1).$$

A simple relationship exists between frequency and wavelength via the wave speed. The wave pattern travels a distance λ over a time of one period *T*. The speed of the wave *v*, is given by equation (2) and (3),

$$v = \frac{\lambda}{T} \qquad (2),$$

$$v = \lambda f \qquad (3).$$

For Part I of the experiment the waves on the string will have a constant speed. By solving equation (3) for frequency, an expression is obtained for frequency as a function of wavelength. In this expression, equation (4), the constant wave speed is represented by *C*,

$$f = C\lambda^{-1} \qquad (4).$$

The data collected for Part IA will be graphed with the frequency as a function of wavelength, as in equation (4). The constant wave speed can them be determine from the best fit statistical equation on the graphed data.

In the set up for this lab, the waves originating from the oscillator reach the fixed end of the string fairly soon, where they are reflected. The reflected waves are simultaneously traveling in the opposite direction to the original waves on the string. The multiple waves traveling in opposite directions combine together following the principle of superposition. The pattern of the observed waves is the result of adding all individual wave functions. At some locations, the individual waves combine constructively and at other locations, the waves combine destructively. If the proper relationship exists between the frequency, the string length, the string density and string tension, then a standing wave is produced. When conditions are such as to make the amplitude of the standing wave antinodes a maximum, the system is said to be in resonance.

When viewing a standing wave at resonance there are locations along the string that do not appear to move, these are known as nodes. Midway between two consecutive nodes there are locations that move the maximum and reach the greatest amplitude, they are called antinodes. See **Figure 3**. The distance between two consecutive nodes is also called the internodal distance. During the lab the internodal distance can be measured and used to determine the wavelength.

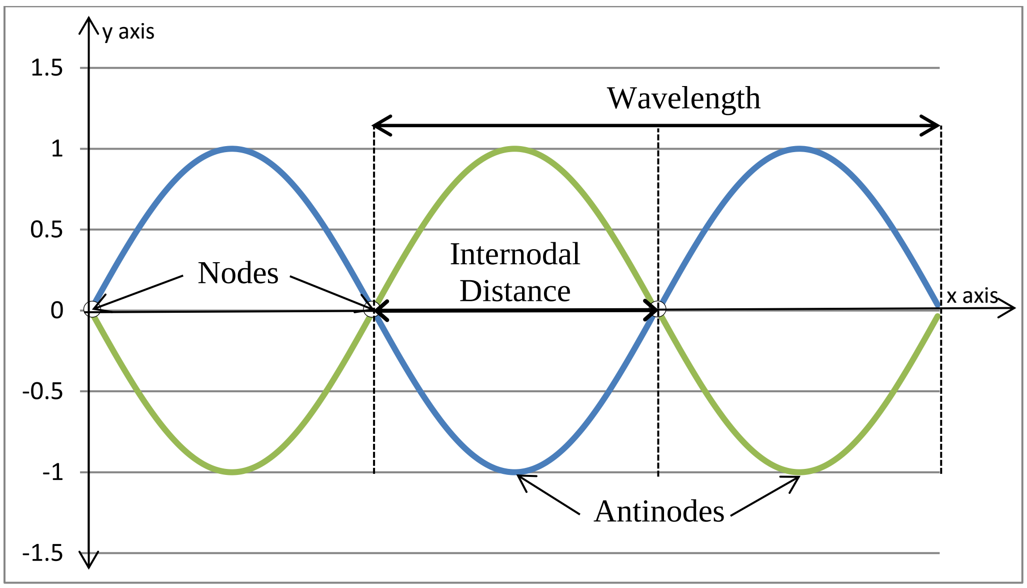

Figure 3

In order for a mechanical wave to exist, it requires some type of matter to exist in. Mechanical waves cannot move through a vacuum. (Note: Light is not a mechanical wave and does move through a vacuum.) The speed at which a mechanical wave travels through a material depends on properties of the material. As an example, the wave traveling down a string, as in Part I of this experiment, will have a different speed than a wave traveling down a metal guitar string.

The physical properties of the string that control the wave speed are the string's linear mass density and the string's tension. Linear mass density μ, is the mass of the string m, per unit length l, as in equation (5),

$$\mu = \frac{m}{l} \qquad (5).$$

As a wave travels along the string, the wave (not the string) has horizontal momentum. Typically the momentum of an object is determined by multiplying the mass of the object times the velocity the object is traveling at. Applying this idea to the wave, the velocity would be represented by the wave speed and the mass would be represented by the linear mass density of the string. The linear mass density is the element of mass that the traveling wave is moving through at any moment of time. Now if the momentum of the wave was considered to be constant and the linear mass density of the string was to increase, then the wave speed would correspondingly decrease. Or in other words, as the wave moves through the material if the density of the material increases, the wave speed would decrease, or if the density decreases and wave speed would increase. Therefore for any given material the density of the material would have an inverse effect on the speed of a wave traveling through the material.

The string's tension *F*, describes how tightly connected each particle of the string is to its neighbors on each side. Since the propagation of the wave occurs from particle to particle in the material, if the connection between string particles is more tightly bound then the wave's movement from one particle to the next will be faster and the wave speed will be greater. If the string particles are less tightly bound, as in less tension, then the wave's movement from string particle to particle will be slower and the wave speed will be less.

Combining these two factors, string mass density and tension, they're relate to the wave speed by the following expression equation (6),

$$v = \sqrt{\frac{F}{\mu}} \qquad (6).$$

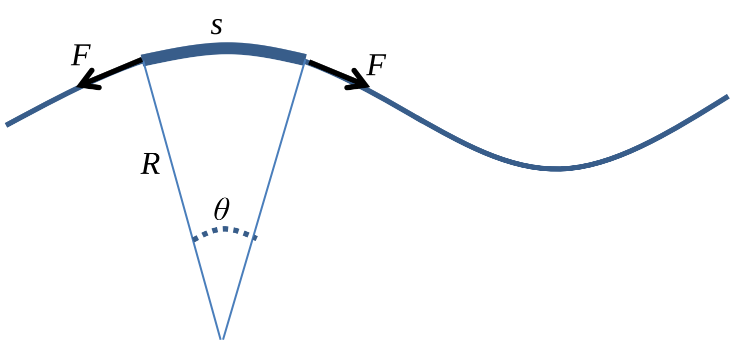

Figure 4

There are several methods to derive equation (6). Please read the derivation provided in your textbook. Here is another method, less rigors, that uses a few approximations. In **Figure 4** the angle θ in units of radians could be determined by dividing the arc length *s* by the radius *R*,

$$\theta = \frac{s}{R} \qquad (7).$$

The string tension *F*, pulling on both sides of the string segment *s*, is analyzed in **Figure 5**,

$$\sum F_x = F\cos\tfrac{\theta}{2} - F\cos\tfrac{\theta}{2} = 0 \qquad (8),$$
$$\sum F_y = -F\sin\tfrac{\theta}{2} - F\sin\tfrac{\theta}{2} = F_{net} \qquad (9).$$

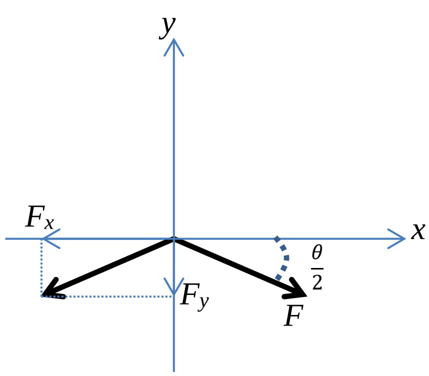

Figure 5

The tension components along the x-axis cancel but the tensions components along the y-axis combine. Now using an analogy that since the string segment has a net force perpendicular to a tangent line at that point on the string it can be considered similar to a centripetal force. Therefore, the net force represents the source of a centripetal like force F_c exerted on the string segment,

$$F_c = \frac{mv^2}{R} \qquad (10).$$

Also since only a segment of string is being analyzed the mass would be represented by,

$$m = \mu s = \mu\theta R \qquad (11).$$

Combining equations (9), (10), and (11);

$$2F \sin\tfrac{\theta}{2} = \mu\theta v^2 \qquad (12).$$

Next using the approximation that when angles are small;

$$\sin\varphi \cong \varphi \quad \therefore \quad \sin\tfrac{\theta}{2} \cong \frac{\theta}{2} \qquad (13),$$

and combining with equation (12);

$$2F\tfrac{\theta}{2} = \mu\theta v^2 \qquad (14),$$

$$F = \mu v^2 \qquad (15),$$

$$v = \sqrt{\frac{F}{\mu}} \qquad (16).$$

Equation (16) is the same as equation (6), indicating the wave speed is dependent upon the tension in the string and the string's linear mass density.

For the string with both ends attached, when resonance occurs, there is always a node located at the fixed ends. This could happen when the resonance length corresponds to a half wavelength. It would happen again when the resonance length corresponds to a full wavelength. This sequence would continue at every half wavelength. In other words the length, *L*, of the string from oscillator rod to pulley, must be an integer number of half-wavelengths, λ, therefore,

$$\lambda_n = \frac{2L}{n} \qquad (n = 1, 2, 3, \ldots) \qquad (17).$$

The mechanical waves in Part II are called longitudinal waves. Here the matter that the wave moves through is displaced parallel to the wave's direction of travel. As an example examine **Figure 6** where a longitudinal wave is traveling through a slinky**.** In this experiment, sound waves are the longitudinal waves being used, which are also known as compressional waves. The sound wave produces pressure differences in the medium, in this case the air. These pressure variations cause movement and therefore displacement of the air molecules. The regions where the pressure is low, called rarefaction, will allow the air molecule displacement to be a maximum. The regions where the pressure is high, called compression, will limit the air molecule displacement to a minimum.

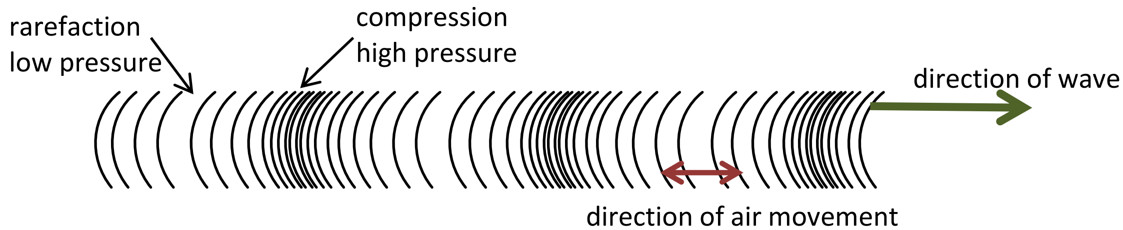

Figure 6

For longitudinal waves the equation relating the speed of the wave to its wavelength and frequency remains the same as for transverse waves (see equation 3). Also like the transverse waves the wave speed is dependent upon properties of the matter the wave is moving through. There is a generalized expression for the speed of a mechanical wave given by equation (18),

$$v = \sqrt{\frac{\text{restoring force returning the system to equilibrium}}{\text{Inertia resisting the return to equilibrium}}} \qquad (18).$$

This may also be written in the form,

$$v = \sqrt{\frac{\beta}{\rho}} \qquad (19),$$

where β is the bulk modulus for a fluid or Young's modulus for a solid and ρ is the density of the matter. For a gas, instead of having fixed molecules with bonds between them, the wave must propagate through collisions between air molecules. One standard approach for developing an expression for the speed of a wave in a gas is to apply the kinetic theory of gas on an ideal gas in an adiabatic process. Initially the kinetic theory of gas leads to the translational root mean square velocity of the monoatomic ideal gas molecules, given by equation (20);

$$v_{rms} = \sqrt{\frac{3RT}{M}} \qquad (20),$$

where R is the gas constant, T is the temperature and M is the molar mass of the gas. This doesn't give the exact right expression for the wave speed of sound in a gas, but it is close and indicates that the main factor influencing the speed is the temperature. Besides the average temperature of the gas influencing the mean velocity, the pressure variations that occur as a sound wave travels through the gas also have an effect. In the regions where low pressure rarefactions occur, the expansion of the gas reduces the temperature by a small amount. Also in the regions where the high pressure compressions occur, the temperature increases by a small amount. Since these regions are distant to each other and because gas is a poor conductor of heat the process can be considered adiabatic. Taking this additional thermodynamic process into consideration, the adjustment is made by using the ratio of the heat capacities,

$$\gamma = \frac{heat\ capacity_{constanct\ pressure}}{heat\ capacity_{constant\ volume}} \quad (21).$$

Applying this correction to equation (20) the speed of sound in a gas is given by,

$$v = \sqrt{\frac{\gamma RT}{M}} \qquad (22).$$

Again one of the differences to notice here is that only the air temperature is going to alter the wave speed for sound whereas in Part I, the string's wave speed could be changed by altering the string density or the string tension. Air is primarily composed of Nitrogen and Oxygen, both are diatomic molecules. The ratio of heat capacities for a diatomic molecule is γ = 1.40. Air is almost 80% Nitrogen which has a molar mass of 14 g/mol and 20%Oxygen which has a molar mass of 16 g/mol. But remember these are diatomic molecules. Combining these parameters gives air a molar mass of M = 28.8x10^{-3} kg/mole. The gas constant has a value of R = 8.31446212 Joules/(mole Kelvin).

Another similarity between the mechanical waves through the string and the sound waves is the occurrence of standing waves. When the conditions were correct for the waves on the string to reinforce each other, thereby increasing the amplitude of the wave, they produced standing waves. Sound waves have similar conditions that when met will also produce standing waves. But with sound this is more often referred to as creating resonance. As a sound wave travels through a media and encounters another object, the oscillations from the sound wave are transmitted into the other object. If the natural resonance frequency of that object is the same as the sound's frequency then resonance will occur. With resonance, like with the standing waves on the string, there is increased amplitude of the antinode.

Although sound is a compressional wave and can be modeled with a sine and/or cosine function, another frequently used approach is using the air's displacement which can also be modeled as a sine and/or cosine function. When resonance occurs, the locations where the pressure is highest will result in the least air displacement and correspond to displacement nodes. The locations where the pressure is lowest will result in the greatest air displacement and correspond to displacement antinodes. For the air columns being used in Part II of the experiment these nodes and antinodes occur in different places depending on whether both ends of the tubes are open, or one end is closed and one end is open. See **Figure 7 & 8**.

Glass Tube Open at Both Ends:

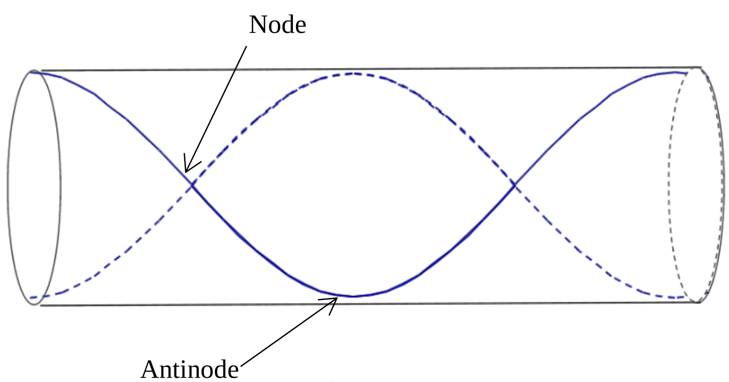

Figure 7

Glass Tube Closed at One End and Open at One End:

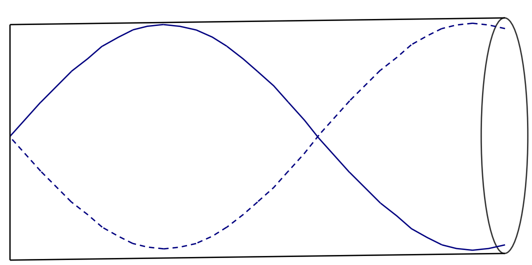

Figure 8

In Part I, the standing waves of the string, the wavelength was related to the length of the string between the oscillator and the pulley. Similarly, the longitudinal waves in Part II, represented by the sound waves, also have the wavelength related to the length of the resonance tube. Specifically, the resonance tube is the air column enclosed by the glass tube.

For a tube with both ends open, when resonance occurs, there is always a displacement antinode located at the open ends. This could happen when the resonance length corresponds to a half wavelength. It would happen again when the resonance length corresponds to a full wavelength.

This sequence would continue at every half wavelength. In other words the length, *L*, of the resonance column must be an integer number of half-wavelengths, λ, therefore,

$$\lambda_n = \frac{2L}{n} \qquad (n = 1, 2, 3, \ldots) \qquad (23).$$

Equation (23) is for the tube with both ends open and is used to calculate the wavelength when the condition for resonance is met. Also notice that this is the same relationship as the string in Part I with both the ends fixed. The difference being that the ends had nodes instead of antinodes, but the reoccurring pattern was the same every half wavelength.

For a tube with one end closed and the other end open, the closed end is always a displacement node. But the open end is still a displacement antinode. In this tube the first time resonance would occur is when the length corresponded to a quarter of a wavelength. The second resonance occurrence would correspond to the tube length being three quarters of a wavelength. There is again a reoccurring sequence that the length of the resonance tube must correspond to an odd-integer multiple of a quarter wavelength, therefore,

$$\lambda_n = \frac{4L}{n} \qquad (n = 1, 3, 5, \ldots) \qquad (24).$$

Equation (24) is used for the tube with one end closed and one end open, to calculate the wavelength when the condition for resonance is met.

Note: There is a correction necessary for the length of the resonance column before calculating the wavelength. Since sound is a compressional wave traveling through the air column, the pressure variations in the wave result in the displacement antinode at the open end of the tube occurring slightly beyond the end of tube. Empirically it has been determined that this distance beyond the end of the tube is largely dependent on the diameter of the tube. The correction to the length, called the end correction factor (*EFC*), is given by equation (25);

$$ECF = 0.6 * r \qquad (25),$$

where *r* is the inside radius of the tube. For a tube with one end closed and one opened, the corrected length can be calculated as:

$$Length_{corrected} = Length_{Tube} + ECF \qquad (26).$$

For a tube with both ends opened this *ECF* will need to be applied to both open ends. Then the corrected length will be:

$$Length_{corrected} = Length_{Tube} + 2ECF \qquad (27).$$

Please read the relevant material in your textbook for this experiment.

Mechanical Waves,	Sears and Zemansky, **University Physics**, *Chapter* **15**.
Speed of Transverse Wave,	Sears and Zemansky. **University Physics**, *Chapter* **15** *section* **4.**
Standing Waves on a String,	Sears and Zemansky. **University Physics**, *Chapter* **15** *section* **7.**
Sound and Hearing,	Sears and Zemansky, **University Physics**, *Chapter* **16**.
Speed of Sound,	Sears and Zemansky. **University Physics**, *Chapter* **16** *section* **2.**
Standing Sound Waves,	Sears and Zemansky. **University Physics**, *Chapter* **16** *section* **4.**

Procedures:

Part IA: Constant Wave Speed with String 1

1. Measure the mass and length of the first string. Note the strings in this experiment are very light so measure the mass with precision to a ten-thousandth of a gram. Measure the string length with precision to a millimeter. Record the measurements on Table 1.
2. Tie one side of the string to the post attached to the table and place the other side over the pulley.
3. Measure the mass hanger with a 20 gram mass added and suspend it on the loose end of the string over the pulley.
4. Measure the distance from the center of the oscillation rod to the center of the pulley. This will correspond to the internodal distance for a standing wave of one loop.
5. Open the corresponding data collection program and have a lab instructor give you instructions about the oscillator and the function generator. If necessary, connect the oscillatory to the function generator (computer interface).
6. Adjust the frequency of the function generator until the string oscillates with a standing wave of one loop. **The frequency must be adjusted first to the precision of a Hertz (1 Hz) and then, tune it to the tenth of a Hertz (0.1Hz)**. Record the oscillation frequency, the number of loops, and the internodal distance.
7. Repeat step 6 for standing waves of 2, 3, 4 and 5 loops. Record all of the information on Table 1.

Part IB: Constant Wavelength with String 1

8. Begin this trial with the same mass on the mass hanger, 20 grams, as in Part IA.
9. To start adjust the oscillation frequency to 50.0 Hz.
10. Now slowly adjust the oscillation frequency until the string oscillates with a standing wave of three loops having the maximum amplitude. Again, looking for the frequency with precision of a tenth of a Hertz.
11. Determine the internodal distance.
12. Record the total hanging mass, the number of loops, the frequency and the internodal distance in Table 2.
13. Add 10 grams to the prior mass on the hanger and measure. Repeat steps 9 thru 12.
14. Add another 10 grams to the masses on the hanger and measure. Again, repeat steps 9 - 12.

Part IC: Constant Wave Speed with String 2

15. Measure the mass and length of the second string. Note the strings in this experiment are very light so measure the mass with precision to a ten-thousandth of a gram. Measure the string length with precision to a millimeter. Record the measurements on Table 3.
16. Tie one side of the string to the post attached to the table and place the other side over the pulley.
17. Suspend the mass hanger with a 20 gram mass added on the loose end of the string over the pulley.
18. Measure the distance from the center of the oscillation rod to the center of the pulley.
19. Adjust the frequency of the function generator until the string oscillates with a standing wave of one loop. Again, looking for the frequency with precision of a tenth of a Hertz. Record the oscillation frequency, the number of loops, and the internodal distance.

20. Repeat step 19 for standing waves of 2 and 3 loops. Record all of the information on Table 3.

Part IIA: Resonance with Sound Waves in an Open Tube

1. Begin with both ends of the tube open.
2. Measure the inside diameter of the tube with a caliper.
3. Measure the length of the tube.
4. Connect the speaker to the function generator (computer interface).
5. On the computer, set the amplitude of the output to 1V/div.
6. Begin with the function generator frequency set at 100 Hz.
7. Slowly increase the frequency on the function generator to find the first resonant frequency. This may be more easily determined by maximizing the amplitude of the output wave. This is given by the sound sensor and displayed on the oscilloscope. It may be necessary to increase and then decrease the frequency several times in small steps to determine the exact resonance frequency. Be precise to the 1 Hz. This resonance frequency will correspond to $n = 1$.
8. Record the frequency in Table 4.
9. Repeat step 7 increasing the frequency until a second resonance occurrence is determined. This will correspond to $n = 2$.
10. Repeat step 7 for a total of five trials with increasing frequency. The trials will correspond to $n = 1, 2, 3, 4$ and 5. Each increasing value of n corresponds to higher frequencies. All frequencies including $n = 5$ will remain below 1000 Hz.

Part IIB: Resonance with Sound Waves in an Open/Closed Tube

11. Close the end of the tube opposite the speaker with the rubber stopper.
12. Measure the length of the air column inside the tube, which corresponds to the tube length minus the depth the rubber stopper goes into the tube.
13. Again, set the amplitude of the output to 1V/div.
14. Also again, begin with the function generator frequency set at 100 Hz.
15. Slowly increase the frequency on the function generator to find the first resonant frequency. This may be more easily determined by maximizing the amplitude of the output wave given by the sound sensor and displayed on the oscilloscope. It may be necessary to increase and then decrease the frequency several times in small steps to determine the exact resonance frequency. Be precise to the 1 Hz. This resonance frequency will correspond to $n = 3$.
16. Record the frequency in Table 5.
17. Repeat step 15 increasing the frequency until a second resonance occurrence is determined. This will correspond to $n = 5$.
18. Repeat step 15 for a total of five trials with increasing frequency. The trials will correspond to $n = 3, 5, 7, 9$ and 11. Again all frequencies will remain between 100 and 1000 Hz.

Analysis:

Part IA: Constant Wave Speed String 1 Table 1

1. Calculate the linear density of the string in units of (kg/m), Equation (5).
2. Calculate the tension in the string due to the hanging mass and hanger.
3. Calculate the wavelength of the standing wave using the internodal distance, Equation (17).
4. Graph the frequency of the wave as a function of the wavelength using Excel.
5. Choose the appropriate trendline fit in Excel for the data, Equation (4). Next use the equation of the fit to determine the experimental wave speed.
6. Calculate the value of the wave speed using Equation (6).
7. Calculate the percent difference between the wave speeds.

Part IB: Constant Wavelength Table 2

8. Calculate the wavelength, Equation (17).
9. Calculate the tension in the string for each trial due to the hanging mass and hanger.
10. Calculate the wave speed for each trial using Equation (3).
11. Calculate the wave speed for each trial using Equation (6).

Part IC: Constant Wave Speed String 2 Table 3

12. Calculate the linear density of the string in units of (kg/m), Equation (5).
13. Calculate the tension in the string due to the hanging mass and hanger.
14. Calculate the wavelength of the standing wave, Equation (17).
15. Calculate the value of the wave speed using Equation (3).
16. Calculate the value of the wave speed using Equation (6).

Part IIA: Resonance with Sound Waves in an Open Tube Table 4

1. Calculate the inside radius of the tube.
2. Calculate the end correction factor, Equation (25).
3. Calculate the corrected tube length, Equation (27).
4. Calculate the theoretical speed of sound as it depends on the temperature, Equation (22).
5. Calculate the wavelength using the necessary equations, Equation (23).
6. Calculate the sound speed using Equation (3).

Part IIB: Resonance with Sound Waves in an Open/Closed Tube Table 5

1. Calculate the inside radius of the tube.
2. Calculate the end correction factor, Equation (25).
3. Calculate the corrected tube length, Equation (26).
4. Calculate the theoretical speed of sound as it depends on the temperature, Equation (22).
5. Calculate the wavelength using the necessary equations, Equation (24).
6. Calculate the sound speed using Equation (3).

Experiment S10a: Mechanical Waves

Student Name____

*Lab Partner Name*____

*Lab Partner Name*____

Physics Course____

Physics Professor______________________________________

Experiment Start Date__________________________________

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheet 1: Part IA: S10a: Mechanical Waves

NAME: ______________________________ DATE: __________________

Table 1: Constant Wave Speed String 1

String Mass (kg)	String Length (m)	String Linear Density (kg/m)
____________	____________	____________

Hanging Mass with Hanger (kg)	Tension in String (N)
____________	____________

Frequency (Hz)	# Loops	Internodal Distance (m)	Wavelength (m)
	1		
	2		
	3		
	4		
	5		

Equation from Graph	Wave Speed from Graph
____________	____________
Wave Speed from Equation (6)	**% difference**
____________	____________

Data Sheet 2: Part IB: S10a: Mechanical Waves

NAME: ____________________________ DATE: _________________

Table 2: Constant Wavelength String 1

# of loops	Internodal Distance (m)	Wavelength (m)
______________	______________	______________

Mass (kg)	Tension (N)	Frequency (Hz)	Equation (3) Wave Speed (m/s)	Equation (6) Wave Speed (m/s)

Data Sheet 3: Part IC: S10a: Mechanical Waves

NAME: ____________________________ DATE: _________________

Table 3: Constant Wave Speed String 2

<table>
<tr><td colspan="2">String Mass (kg)
________________</td><td colspan="2">String Length (m)
________________</td><td colspan="2">String Linear Density (kg/m)
________________</td></tr>
<tr><td colspan="3">Hanging Mass with Hanger (kg)
________________</td><td colspan="3">Tension in String (N)
________________</td></tr>
<tr><td># of loops</td><td>Internodal Distance (m)</td><td>Wavelength (m)</td><td>Frequency (Hz)</td><td>Equation (3) Wave Speed (m/s)</td><td>Equation (6) Wave Speed (m/s)</td></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Data Sheet 4: Part IIA: S10a: Mechanical Waves

NAME: ____________________________ DATE: _________________

Table 4: Resonance with Sound Waves in an Open Tube

<table>
<tr><td colspan="6">Room Temperature (^{o}C)

_________________</td><td colspan="6">Theoretical Sound Speed (m/s)

_________________</td></tr>
<tr><td colspan="4">Tube Diameter (m)

_________________</td><td colspan="4">Tube Radius (m)

_________________</td><td colspan="4">End Correction Factor (m)

_________________</td></tr>
<tr><td colspan="6">Tube Length (m)

_________________</td><td colspan="6">Corrected Tube Length (m)

_________________</td></tr>
<tr><td colspan="3">n</td><td colspan="3">Frequency (Hz)</td><td colspan="3">Wavelength (m)</td><td colspan="3">Sound Speed (m/s)</td></tr>
<tr><td colspan="3">1</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="3">2</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="3">3</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="3">4</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="3">5</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
</table>

Data Sheet 5: Part IIB: S10a: Mechanical Waves

NAME: ______________________________ DATE: __________________

Table 5: Resonance with Sound Waves in an Open/Closed Tube

<table>
<tr><td colspan="6">Room Temperature (^{o}C)

____________________</td><td colspan="6">Theoretical Sound Speed (m/s)

____________________</td></tr>
<tr><td colspan="4">Tube Diameter (m)

____________________</td><td colspan="4">Tube Radius (m)

____________________</td><td colspan="4">End Correction Factor (m)

____________________</td></tr>
<tr><td colspan="6">Tube Length (m)

____________________</td><td colspan="6">Corrected Tube Length (m)

____________________</td></tr>
<tr><td colspan="3">n</td><td colspan="3">Frequency (Hz)</td><td colspan="3">Wavelength (m)</td><td colspan="3">Sound Speed (m/s)</td></tr>
<tr><td colspan="3">3</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="3">5</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
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<tr><td colspan="3">11</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
</table>