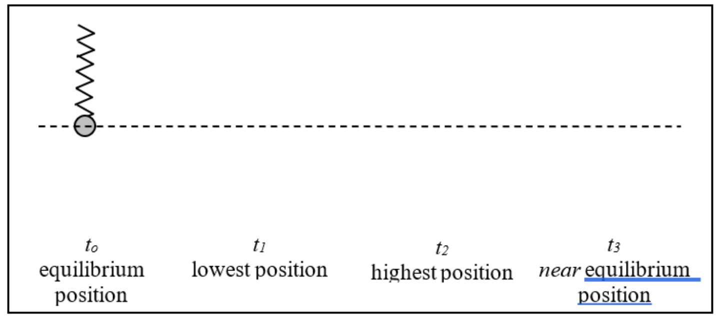
SPH3U: Good Vibrations

A: Amplitude and Period of Oscillations

Your teacher will use a metal spring (or elastic) and a small attached object attached to demonstrate *oscillation*, which is an example of periodic motion. This is motion that repeats itself in a regular pattern.



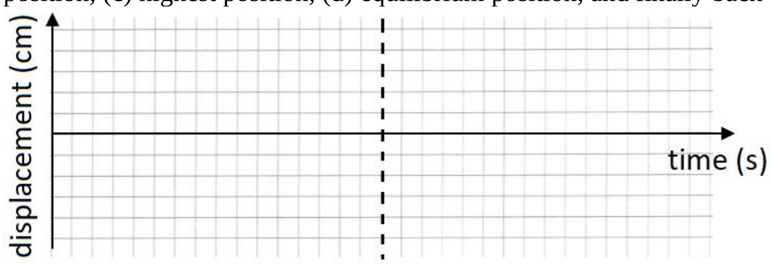
1. In the diagram to the right, draw three images of the spring and moving object at the indicated moments.

2. Draw a vector for each moment in time carefully showing the object's displacement from equilibrium.

The largest displacement of the object from equilibrium is the *amplitude*. A *cycle* is one complete oscillation, starting and ending at the same position after completing one whole motion. The time to complete one cycle is the *period* (T).

3. Measure the *amplitude* and *period* of the oscillating object.

4. Plot ***two*** full cycles of the oscillation on the graph. Each cycle should consist of five points: (a) lowest position, (b) equilibrium position, (c) highest position, (d) equilibrium position, and finally back to (e) lowest position. Draw a smooth curve.

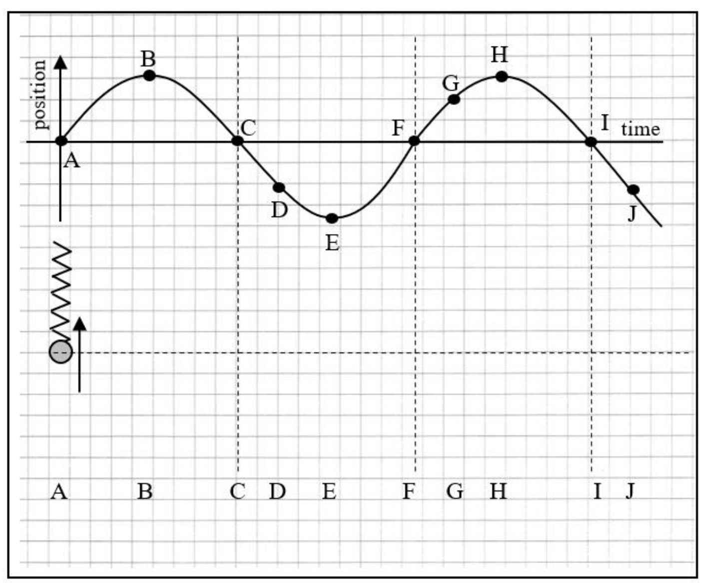


5. How many cycles does your object go through in one second of time? You can use your data from question #3.

The *frequency* of periodic motion (f) is the number of cycles of the motion per unit of time, given by f = (*# of cycles*)/*time*. The units of frequency are *hertz* (Hz) and mean "cycles per second". Frequency and period are related by: $f = 1/T$ or $T = 1/f$.

B: Phase

Consider the graph, showing an oscillating object.



1. Draw the position of the object and spring according to the graph for each labeled moment in time.

2. Draw an *instantaneous* velocity vector below each image of the object. If it is zero, write a zero.

The *phase* of a particle in periodic motion can be described by its position and velocity. When two points have the same position and velocity, we call them *"in phase"*, otherwise they are "*out of phase*" When two states are half a cycle apart they have *opposite phase*.

3. Find all the points which have the same phase as:

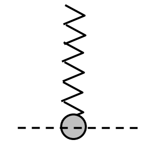
B:	C:	D:

4. Find all the points which have the opposite phase as:

A:	B:	D:

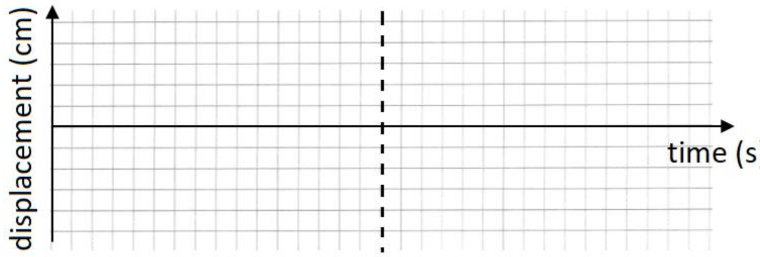
SPH3U: Good Vibrations Homework   Name:

A: The Follow the Bouncing Ball



A ball attached to a spring. You pull down the ball and release it. It vibrates up and down with a steady, repeating motion. You measure that it takes 0.73 s to complete one cycle of its motion. During that time, the farthest distance it travels from the equilibrium position is 5.7 cm.

1. **Represent.** Draw a position-time graph for the ball starting at the moment you release the ball. Label and give the values for its period and amplitude.



2. **Calculate.** What distance does the ball travel in one cycle? What is its average speed?

3. **Calculate.** What is the displacement of the ball during one cycle? What is its average velocity?

4. **Reason.** At which moments is the ball traveling the fastest? The slowest?

5. **Calculate.** What is the frequency of the ball's motion?

B: The Teeter-Totter

Who doesn't like playing on the teeter-totter in the local park? Two kids are bouncing away and you measure that they bounce up and down 10 times in 17.9 s.

1. **Calculate.** What is the period and frequency of their motion?

2. **Reason.** Two larger kids get on and start bouncing. Will the period increase or decrease? Explain.

3. **Reason.** With the new, older kids, the period of the teeter-totter is now double what it was before. Explain (don't calculate) how the frequency will change.

4. **Reason.** How does the phase of the two kids who are bouncing together on the teeter totter compare with one another?

SPH3U: Making Waves

In our work so far, we have had only one particle to keep track of. Imagine now that we connect a whole series of particles together such that the movement of one particle affects the others around it. When we start a vibration in one particle, an effect will travel from one particle to the next – a *wave* has been created.
We will use an online wave simulator to investigate this behaviour: phet.colorado.edu/en/simulation/wave-on-a-string

A: Particle Motion

Make a single pulse, which is single bump above the equilibrium position.

Important Settings:
-"Pulse" mode
-"Damping" to none
-Fixed End

1. Describe the motion of the pulse in the wave machine.

2. Watch one green particle carefully as the pulse travels by it. Compare the direction of a particle's motion with the direction of the wave pulse's motion. Draw a simple illustration.

Pro tip: to get rid of a wave, increase damping briefly

In a *transverse wave*, the particles of the medium oscillate in a direction that is perpendicular to the direction of the wave motion.

Important Settings:
-Loose End

3. Now switch your settings to "Loose End", and send another pulse. Use a diagram to show how the waves with a fixed end and loose end differ.

4. A "snapshot" of a transverse pulse travelling through a wave machine is shown in the diagram to the right. The pulse is traveling to the right at 50 cm/s. Three particles in the medium are marked with tape, A, B, and C. Each square in the diagram is 5.0 cm.
   (a) Between 0.0 s and 0.1 s, in what direction did each particle move?

   (b) How in what direction did the "peak" of the wave move? How far did it travel?

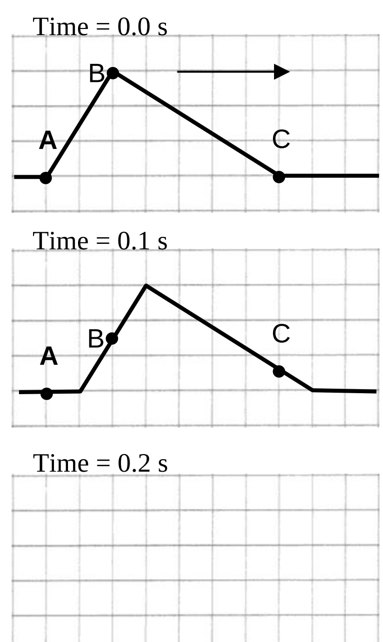
   (c) Draw the pulse and label the position of the three particles at the time of 0.2 s.

   (d) At what time will the complete pulse have passed through particle C?

   (e) What is the total distance that particle C will move by the time the pulse completely passed?

   (f) At what time will particle B return to the rest position?

   (g) What is the average velocity of particle B between t = 0s and t = 0.1 s?



So what exactly is a wave? What is travelling down the string? We'll discuss…

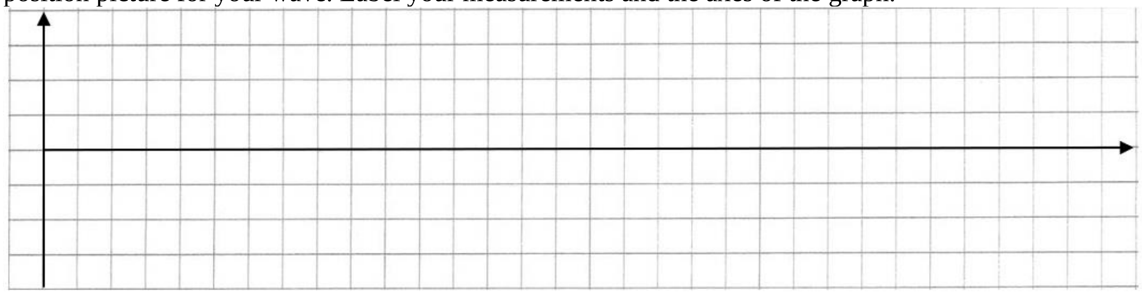
B: The Periodic Wave

Use the settings to the right, and create a single gentle, continuous, periodic wave.

A continuous or *periodic wave* has two parts that we call the *crest* and *trough* of the wave which correspond to the top of the positive and bottom of the negative displacements. The distance the wave travels in one cycle is equal to the distance between the two nearest points of equal phase. This distance is called the *wavelength* and is represented by the greek letter *lambda* (λ). To measure such a distance, you can choose two adjacent crests as the nearest points of equal phase.

Important Settings:
-"Oscillate" mode
-"Damping" to none
-No End

1. Freeze the wave using the pause button. Turn on rulers and measure the amplitude and wavelength of the wave. Then sketch a position picture for your wave. Label your measurements and the axes of the graph.



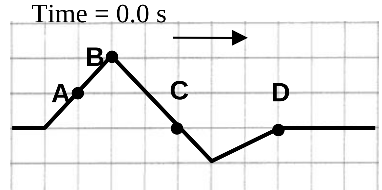
2. Choose one green particle and find the period of the oscillations – in other words, how long for one cycle. Caution – this moves quickly, and trying to measure the time for a single oscillation is not very accurate…try to find a more accurate method.

SPH3U: Making Waves Homework   Name:

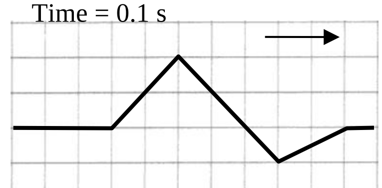
A: Tracking the Particles

A pulse travels through a spring as illustrated in the diagram to the right. Four particles of the spring are labeled A, B, C and D. (Imagine a piece of tape is attached to label those particles.) Each box of the gird represents a distance of 5.0 cm.

Time = 0.0 s



Time = 0.1 s



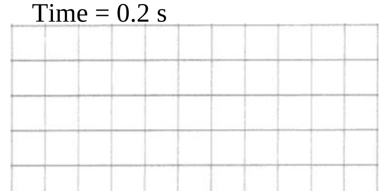
1. **Represent.** The pulse is shown in the second diagram at a time of 0.1 s after the first. Label the four particles A, B, C and D in the second diagram.

2. **Calculate.** What is the speed of the wave?

3. **Interpret.** What distance did particle B move in the interval between 0 and 0.1 s?

4. **Interpret.** At the time of 0 s, what direction is particle A moving in?particle C?

Time = 0.2 s



5. **Represent.** Draw the pulse at a time of 0.2 s. Label the four particles A, B, C and D.

6. **Calculate.** At what time does the pulse completely pass through particle D?

7. **Calculate.** What distance had particle D traveled once the pulse has completely passed by?

8. **Explain.** Explain why this is a transverse wave.

SPH3U: Properties of waves in a coiled spring

How do waves and pulses behave in a coiled spring? We'll continue using phet.colorado.edu/en/simulation/wave-on-a-string

A: Ideal Waves and Pulses

As a real wave or pulse travels or *propagates* through a medium it may gradually change.

1. Create a single pulse with a fixed end, and set the "Damping" to somewhere in the middle. Describe how the pulse changes while it travels back and forth through the medium.

Real waves lose energy as they travel causing their amplitude to decrease. We will always ignore these important and realistic effects and instead focus on studying *ideal waves* in a medium that does not lose energy or cause wave shapes to change.

Set the damping to none for the rest of the investigations.

B: Speed of Waves

Make a pulse which will be your "standard" pulse. Record the amplitude and width of your standard pulse.

1. Can you make your pulse travel slower? Faster? Vary the pulse in a number of different ways and make a rough judgement about the speed – does it appear to travel back and forth faster, slower or the same? Remember to only vary one thing at once.

Characteristic to Vary	Observations
Amplitude	
Wavelength (pulse width)	
Tension	

2. Use a ruler and timer to measure the distance and time the wave travels to a fixed end. Then calculate the wave speed.

Tension	Distance	Time	Speed
High			
Medium			
Low			

D: Wavelength and Frequency

Create a wave (set to oscillate), set the frequency and pause the wave once you have a full wavelength.

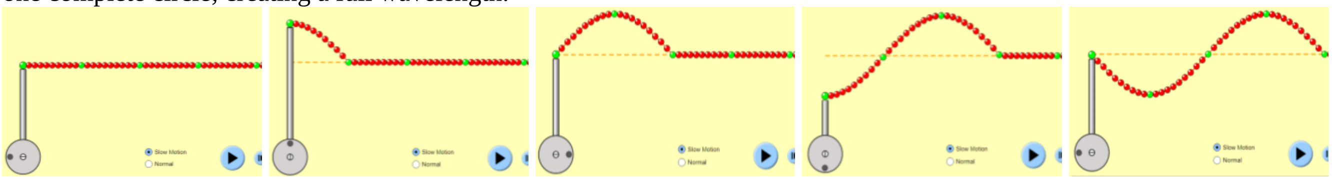
1. How are wavelength and frequency related? (generally speaking…don't need numbers/calculators)

2. Write the relationship between frequency f and period T (if you can't remember, look back to first slide/page of yesterday).

Frequency	Wavelength (measure these using simulation)
0.6 Hz	
1.2 Hz	
2.4 Hz	

E: Speed, Wavelength and Frequency

Let's explore the relationship between speed, wavelength, frequency and period. The diagrams below indicate a disc moving in one complete circle, creating a full wavelength.



1. What fraction of a cycle does the circle/piston move between each picture?

2. What fraction of a wavelength do we see in each diagram? Label these wavelengths on the diagrams.

3. Generally speaking, how far does a wave travel in the time of 1 period?

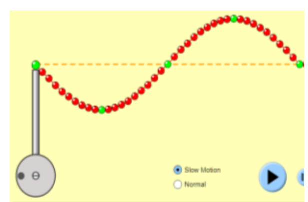
4. Write an equation for the speed of the wave using its period T and wavelength λ. Hint: velocity = distance / time

Pro tip: use the button to go frame by frame

The speed of a wave v (m/s) can also be expressed with the *universal wave equation*, $v = f\lambda$, with frequency f (Hz) and wavelength λ (m). Note that a change in frequency affects the wavelength and vice versa, but **do not affect the wave speed**.

5. Set your wave to oscillate, press play and pause it when you see one full wavelength. Calculate the wave speed using the universal wave equation: $v = f\lambda$. Compare your speeds to those on the previous page. Are they the same?

Tension	wavelength	frequency	Speed
High			
Medium			
Low			



E: Standing Waves

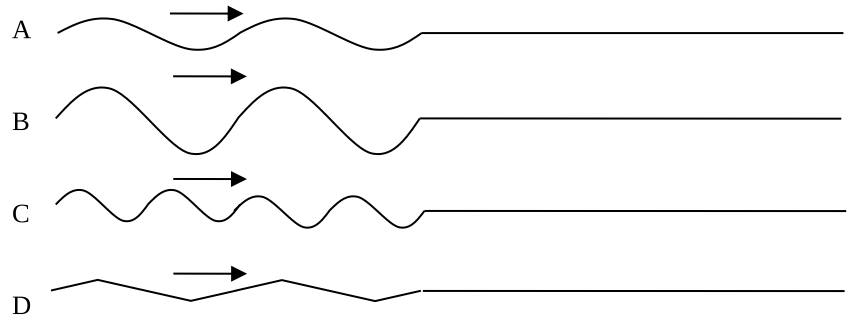
Standing waves are produced when certain points along the wave are not moving very far from the central axis, while other points are moving very far from the axis. The pattern should remain fairly stable.

1. Try to produce different standing waves in your coiled spring by adjusting frequency. It is possible to produce standing waves with different numbers of crests/troughs. What was the frequency in order to produce this pattern? Draw each pattern produced and write down the frequency required to produce the pattern. Standing wave demonstration.

Add a small amount of damping when doing this question, and make sure you have a Fixed End

SPH3U: Properties of Waves Homework Name:

1. **Reason.** Four different waves travel along four identical springs as shown below. All begin travelling at the same time.
   (a) Describe what is different about each wave.



   (b) Rank the amount of time it will take for the four waves to arrive at the ends of the springs. Explain your reasoning.

2. **Reason.** Your friend is sending a wave along a spring and says, "I want the wave to reach the other end of the spring in less time, so all I have to do is shake my hand faster." Do you agree with your friend? Explain.

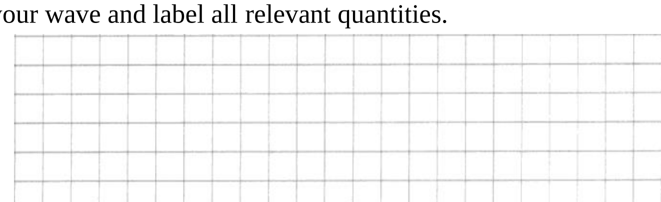
3. **Represent.** You have a spring stretched out 7.3 m along the floor between you and your friend. You shake your hand side-to-side and create a wave that travels down the spring. Your hand starts at the equilibrium position and moves 10 cm to the right, back to the equilibrium, 10 cm to the left and back to the equilibrium position. Your hand executes this three times in a row in 1.2 seconds. Your friend times that it takes 0.84 s for the wave to travel from your hand to your friend's.
   (a) **Calculate and Explain.** What is the period of this wave? Explain how you chose which time values to use.

   (b) **Calculate and Explain.** What is the speed of the wave in this spring? Explain how you chose which distance and time values to use.

   (c) **Calculate and Explain.** What is the amplitude of the wave? Explain how you chose which distance values to use.

   (d) **Calculate and Explain.** What is the wavelength of this wave? Recall: velocity = wavelength / period.

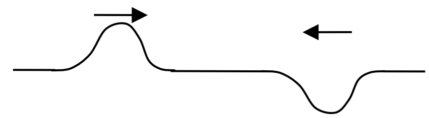
   (e) **Represent.** Sketch a graph of your wave and label all relevant quantities.



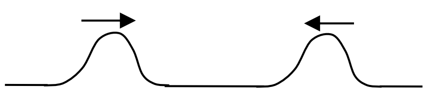
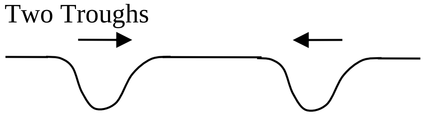
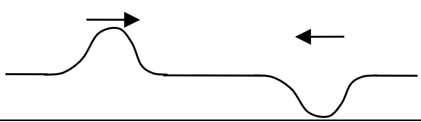
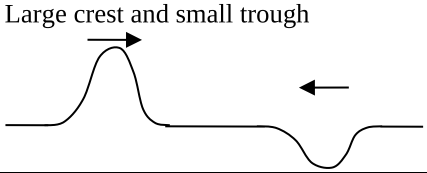
SPH3U: Interference

A: When Waves Meet

1. What happens when two waves travel through the same medium and meet? Suppose two waves are heading towards each other. What might happen? Give some options.



2. Watch the video and draw your observations of the spring when the pulses overlap and after they have overlapped.

Before	Overlapping	After
Two crests 		
Two Troughs 		
Equal crest and trough 		
Large crest and small trough 		

3. Describe what happens when the waves overlap.

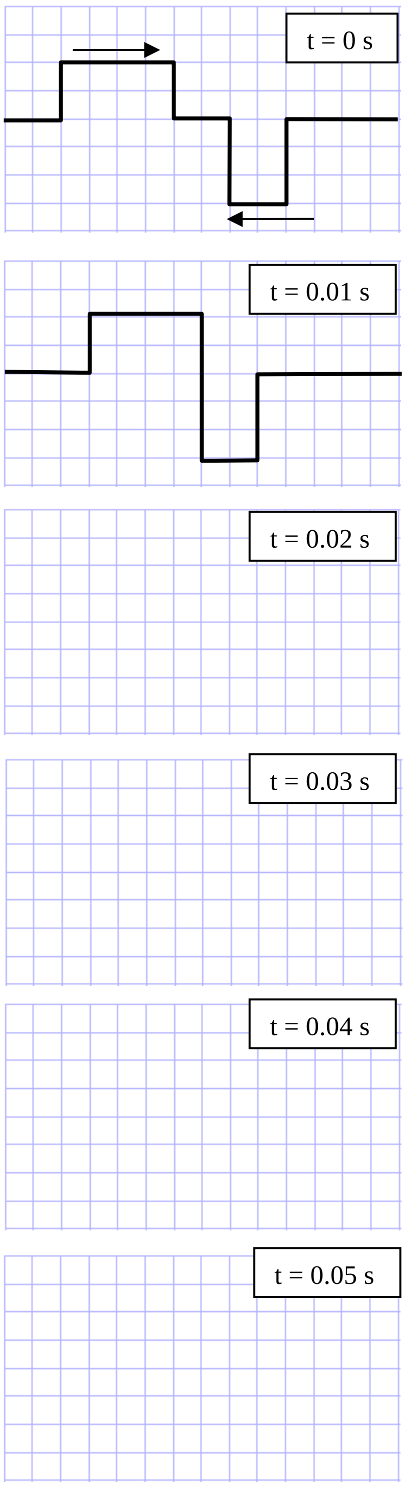
4. Do the waves bounce off one another or do they travel through one another?

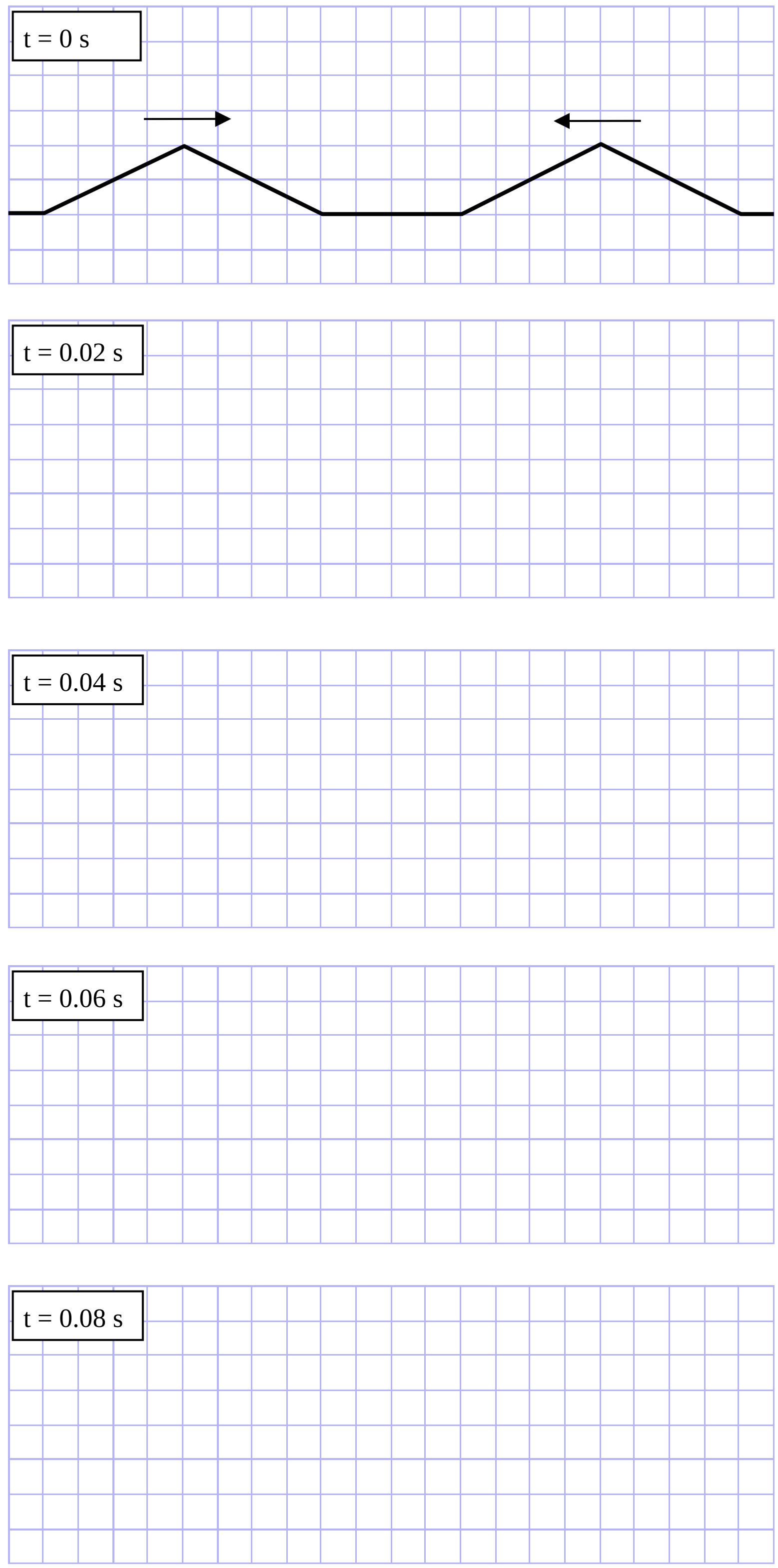
When two ideal waves overlap, one does not in any way alter the travel of the other. While overlapping, the displacement of each particle in the medium is the sum of the two displacements it would have had from each wave independently. This is the *principle of superposition* which describes the combination of overlapping waves or *wave interference*. When a crest overlaps with a crest, a *supercrest* is produced. When a trough and a trough overlap, a *supertrough* is produced. If the result of two waves interfering is a greater displacement in the medium *constructive interference* has occurred. If the result is a smaller displacement, *destructive interference* has occurred.

5. Label each example in the "Overlapping" column of your chart as either constructive or destructive interference.

B: Interference Frozen in Time

Let's apply the principle of superposition to some sample waves and learn how to predict the resulting wave shapes. Each pulse moves with a speed of 100 cm/s. Each block represents 1 cm.



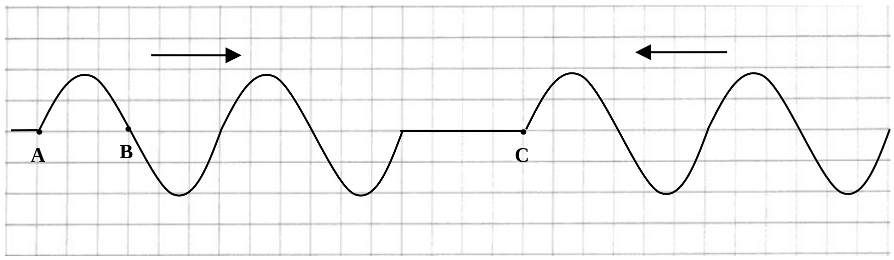


SPH3U: Standing Waves

A: When Continuous Waves Interfere

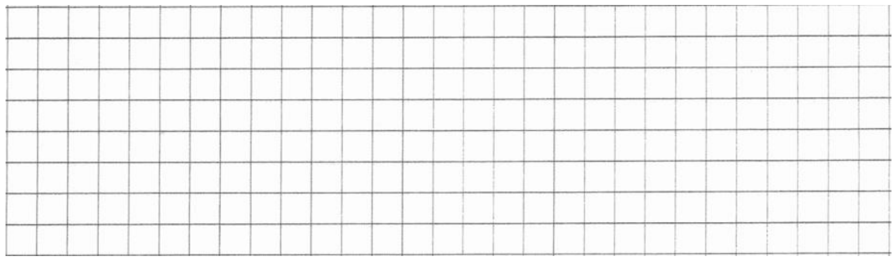
The diagram to the right shows two waves travelling in opposite directions in a spring.

The points A, B, and C are points of constant phase and **travel with the wave**. We will use these to help keep track of the wave.

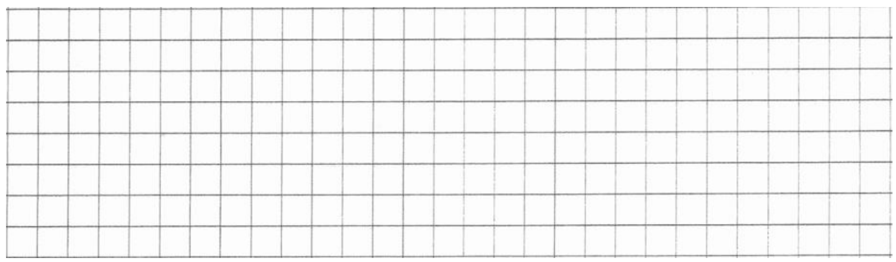


1. Use dotted lines to draw the shapes of the individual waves when points B and C coincide. Draw the displacement of the actual medium using a solid line. You should be able to do this without detailed math work.

   Label the regions where constructive or destructive interference occurs.



2. Use dotted lines to draw the shapes of the individual waves when points A and C coincide. Draw the displacement of the actual medium using a solid line.



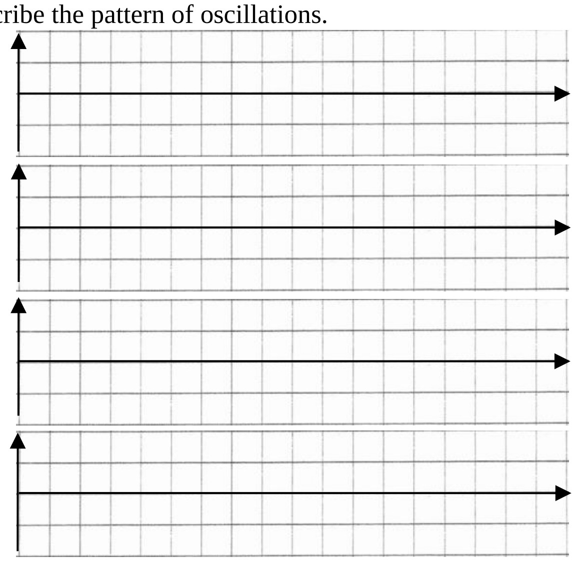
B: Representing Standing Waves

When the interfering process we examined above repeats, a standing wave is created. We will continue to use phet.colorado.edu/en/simulation/wave-on-a-string , this time to make a standing wave.

1. **Reason**. Why do you think the term “standing wave” is used?

2. **Observe.** Do all particles in the medium oscillate equal amounts? Describe the pattern of oscillations.

3. **Observe.** Your teacher will freeze the video to help us study the standing wave pattern at different moments in time, separated by ¼ period. Sketch the displacement of the medium at each moment.



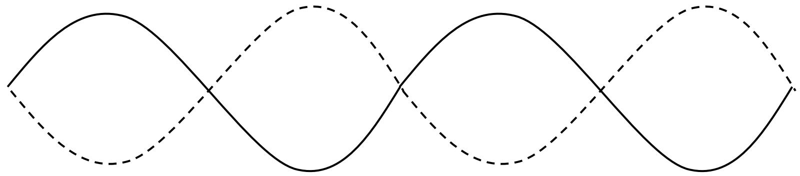
A *standing wave* is a wave pattern created by the interference of two continuous waves travelling in opposite directions in the same medium. It is called a standing wave because there are locations in the medium where the waves always interfere destructively and the particles do not move (or hardly move). These locations are called *nodes* or *minima*. There are other locations where the waves always interfere constructively. These locations are called *antinodes* or *maxima*.

4. **Represent.** Label the locations in the medium where nodes and antinodes are found in your sketches.

Since a standing wave pattern is a moving phenomena, we need a *standing wave diagram* to represent it. In this diagram, we show the wave at the two moments in time when the greatest displacements occur, as shown below.

5. **Represent.** Label locations in the medium where nodes and antinodes occur in the standing wave diagram.

6. **Reason.** What fraction of a cycle has elapsed between the two images of the wave?



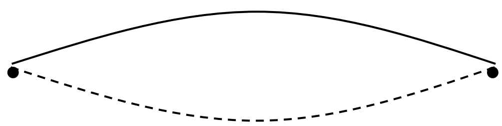
C: Standing Wave Patterns

We will continue using the phet simulation phet.colorado.edu/en/simulation/wave-on-a-string.
Add a VERY small amount of Damping and set Tension to Medium. Set Amplitude to 0.75 m.

1. **Observe.** Start with a very low frequency and gradually increase the driving frequency until it is as high as possible. Try to create some standing waves – you want certain balls to move a lot and others to move just a little.

2. **Observe.** Create a standing wave with the lowest frequency you can manage. You've got the correct pattern if there is only one anti-node. Measure and record the length of the spring and the period of the wave in the table below.

3. **Observe.** Gradually increase the frequency driving the spring until you find the next standing wave pattern or oscillation *harmonic*. Every time, a new node should appear. Measure the period. Repeat this and complete the chart below.

Harmonic/ Mode #	# of Anti-Nodes	# of Nodes	Length (λ)	Diagram
1	1	2	½	
2				
3				

4. **Predict.** What is the standing wave pattern and all its characteristics for the 4th mode. Sketch it below.

$$\lambda_n = \frac{2L}{n}$$

where λ_n=wavelength of n^{th} mode
n = mode #
L = length of medium

Patterns like those above are examples of *resonance*, where a small, periodic driving force can cause an object to vibrate with a large amplitude. An object will *resonate* when the *driving frequency* matches the object's *resonant frequency*. The value of the resonance frequency depends on the composition and construction of the object. If the driving frequency is slightly higher or lower than the resonance frequency, the amplitude of waves in the object is much smaller and the vibrating pattern will not be regular .

SPH3U: Standing Wave / Resonance Homework

A: Pure as the Driven Spring

A spring is stretched out and held fixed on the ground at two points 2.9 m apart. Its wave speed at that length is 4.5 m/s.

1. **Calculate and Explain.** What is the wavelength when vibrating in the first and second harmonics? Explain your result.

2. **Calculate.** What frequency should the student use to create a standing wave in the first and second harmonics?

3. **Explain.** You create a wave that has a wavelength of 84 cm in a spring stretched out to a distance of 126 cm. Will resonance occur? (Will a standing wave be created?) Use a standing wave diagram to help explain.

4. **Calculate and Explain.** The two ends of a spring are held fixed on the ground 5.3 m apart. Waves travel in the spring at 4.7 m/s. A student drives the spring using a frequency of 2.9 Hz. Will resonance occur? Explain how you decide.

5. You have a spring stretched along the floor to a length of 3.9 m.
   (a) **Calculate and Represent.** Draw a standing wave diagram for the first three harmonics. Determine the wavelength of each harmonic.

   (b) **Calculate and Describe.** Waves travel with a speed of 6.1 m/s in your spring. Determine the first three resonant frequencies for your spring. What do you notice about the pattern of frequencies?

	Standing Wave Diagram	λ	f
1			
2			
3			

6. **Reason and Calculate.** You hold one end of a new meter stick against the desk. The length of the vibrating part of the stick is 0.75 m and it vibrates in its first harmonic with a frequency of 5.3 Hz. What are the frequencies of the next two harmonics? (Hint: use the fact that all the lengths are the same)

	Standing Wave Diagram	L=__ λ	f
1			
2			
3			

SPH3U: Resonance

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
R 1 2 3 4

A: The Little Driving Goes a Long Way

Your teacher has a short section of a slinky stretched vertically and fixed at each end. You will make observations as someone provides a *driving force*.

1. **Observe***(as a class)***.** The driver will hold onto a coil of the spring at different positions and produce a transverse vibration. Where is the best position to create a standing wave pattern?

2. **Observe** *(as a class)***.** When the standing wave is produced, how does the amplitude of the driving motion and the amplitude of the standing wave compare?

3. **Represent.**Draw a standing wave diagram for the spring vibrating in the first harmonic. Label the nodes, antinodes and the location you found was best for driving the spring.

4. **Observe***(as a class)***.** Compare the frequency of the driving force and the frequency of the standing wave. What happens if we change the frequency of the driving force by a small amount higher or lower?

A small, periodic driving force can cause an object to vibrate with a large amplitude. This phenomenon is called *resonance*. An objectwill *resonate* when the *driving frequency* matchesthe object's *resonant frequency*.The value of the resonance frequency is determined by its harmonics and depends on the composition and construction of the object. If the driving frequency is slightly higher or lower than the resonance frequency, the response (the amplitude of the waves) in the object ismuch smaller and the vibrating pattern will not be regular.

5. **Explain.** Why is the situation we have just studied an example of resonance?

6. **Speculate.**What characteristics of your spring system do you think determined its resonant frequency?

B: The Natural Frequency

Most objects will vibrate readily at one or more *natural frequencies*. If you tap (snap, pluck, hit) an object and let vibrate freely, if will vibrate at its natural frequency. Usually the natural frequency corresponds to the object's first resonant frequency or *fundamental mode*.

1. **Observe.** Hold a metre stick against the surface of your desk with one part hanging beyond the edge. Pluck the free end of the meter stick. Describe what you observe.

2. **Observe.** What characteristics of the vibrating section of the meter stick can you change to change the natural frequency? Describe what you observe.

3. **Observe.** Choose a set up for your meter stick that produces a natural frequency that you can measure. Explain how you do this and measure this frequency and the characteristic of the system you adjusted.

4. **Represent.** Draw a standing wave diagram for the vibrating portion of the meter stick after your pluck. Label nodes, antinodes and other measurements you made.

5. **Reason.** What fraction of a wavelength is illustrated in your standing wave diagram? Label this by indicating that the length (L) of the vibrating section is equal to some fraction of λ

6. **Calculate.** In class today you measured the natural frequency and length for the meter stick with one end held against your desk. Use these measurements to calculate the wave speed of the meter stick.

7. **Observe.** Now hold the middle of the meter stickacross the corner of your desk. Pluck one end. Describe what you observe. Measure the length of the vibrating system.

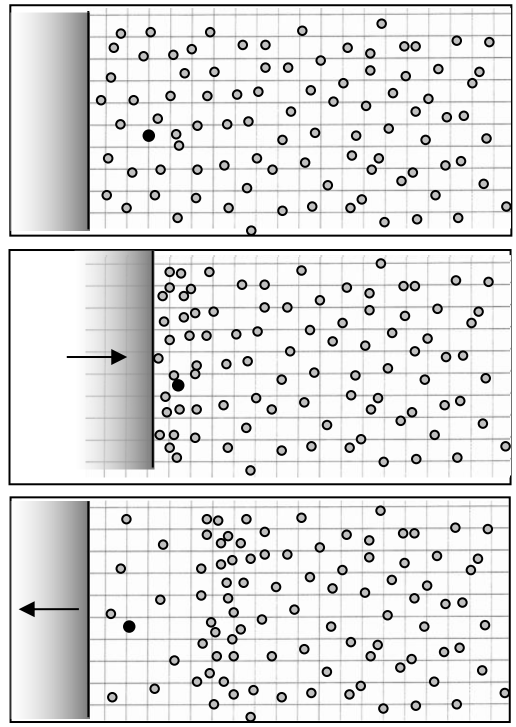
8. **Represent.** Draw a standing wave diagram for the meter stick after your pluck. Label nodes, antinodes and other measurements you made.

9. **Reason.** What fraction of a wavelength is illustrated in your standing wave diagram?

SPH3U: Sound Waves

A: The Sound Wave

A *sound wave* is any kind of longitudinal wave that travels through a medium. The sound waves we are most familiar with are those that travel through air. A vibrating object causes a disturbance in the air particles around it and this disturbance travels outwards as a longitudinal wave.



1. **Observe.** How do the air particles appear to be distributed?

If we could watch a video of these particles, they would be travelling in random directions, bouncing off one another. This is the equilibrium state of the medium of air. When we study longitudinal waves, we will ignore the random vibrations of the air molecules.

2. **Observe.** Now the membrane begins to vibrate. Describe what happens to the spacing of the air particles near the membrane.

3. **Observe.** The membrane now moves in the opposite direction. Describe what happens to the particles near the membrane.

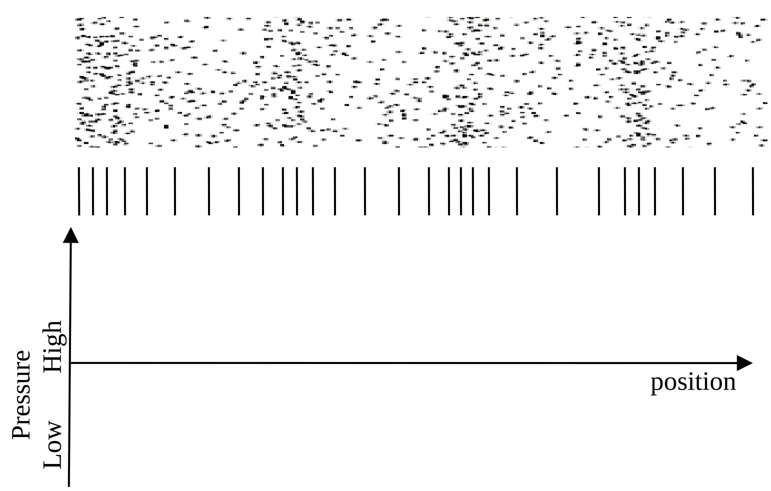
The regions where the medium is compressed have a high air pressure and regions where the medium is rarefied have a low air pressure. Sound is a *pressure wave*. The diagrams above are good illustrations of how a sound wave is created by any vibrating source – not just your headphones!

4. **Represent.** Label the regions of high and low pressure in the diagrams.

5. **Observe.** One air particle has been emphasized in black. Describe its overall motion. Trace its path on the bottom diagram. How does this motion agree with our understanding that sound is a longitudinal wave?

B: Representing Sound Waves

The first diagram to the right shows the air particles involved in a periodic sound wave. The diagram below it shows an identical wave, represented by slinky-type "coils".



1. **Represent.** For both the air particle and slinky-coil diagrams, label the regions of high and low pressure with the letters "H" and "L"

2. **Reason.** Does the interval between two compressions represent the period or wave length in these illustrations? Explain. Label these intervals on the diagrams.

3. **Represent.** Plot on the graph a data point for each high and low pressure region on the diagrams above.

4. **Test.** Use the microphone attached to the computer to verify your predicted pressure graph for a sound wave created by a vibrating tuning fork.

C: FiddlyDee, Dee-Dee, Two Speakers

Your teacher has ***two speakers*** set up at the front of the class that will produce identical sound waves. These two waves will meet and, like all waves, interfere.

1. **Predict.** When the two waves meet and interfere constructively, what do you think you will hear? What if they interfere destructively?

2. **Test.** (*as a class)* Listen carefully and describe what you hear as you move around the room.

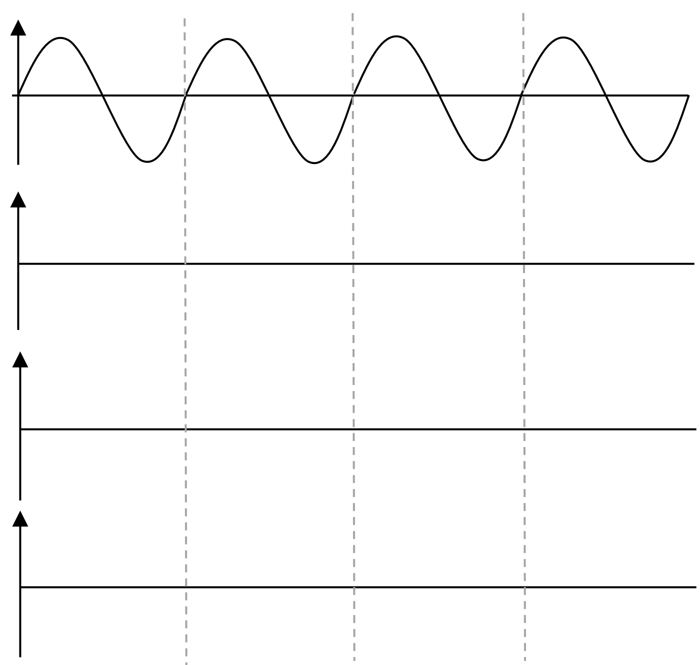
D: The Speed of Sound

The speed of sound in air is given by the equation: $v = 331\ \text{m/s} + \left(0.59\ \frac{m/s}{^{o}C}\right)T$, where T is the air temperature in degrees Celsius.

The warmer it is, the greater the speed of sound. Sound can travel through all sorts of materials – gases (like air), liquids (like water) and solids (like the earth). The speed of sound also depends roughly on the density of the medium the sound waves travel through. A higher density medium generally produces a greater speed of sound.

1. **Calculate.** What is the speed of sound in this room right now? You may need to make a simple measurement.

E: The Characteristics of a Musical Sound



In the graph to the right is a very simple sound wave that we will use for our comparisons. This sound wave is an idealized one, but is very close to that produced by a tuning fork. Answer questions 1-3 below and then we will check your predictions using the computer oscilloscope.

1. We now strike the same tuning fork harder so the sound it makes is *louder* (the only difference). What characteristic of the wave would change? Sketch your prediction to the right.

2. Next we strike a smaller tuning fork that has a higher *pitch*. What characteristic of the wave would change? Sketch your prediction to the right.

3. Finally, we choose a musical instrument and produce a sound with the same pitch and loudness as the tuning fork. Here the sound has a different quality or *timbre.*

4. Define the following terms based on your observations of the computer results.

   (a) loudness:

   (b) pitch:

   (c) timbre:

When a real object like the string on a violin or the air in a flute vibrates, it can vibrate in many modes **at the same time**. These modes or harmonics **interfere** according to the superposition principle and create sound waves with more complex shapes or *waveforms*. The particular combination of harmonics is what gives a musical instrument or a person's voice its distinctiveness. A *pure tone* has very few harmonics and a *complex tone* has many.

F: Beats

Your teacher has ***two large tuning forks attached to resonance boxes*** and one ***additional tuning fork*** at the front of the class.

1. **Observe.** Listen to the sound of the tuning fork with and without a resonance box. Describe what you notice.

2. **Predict.** Your teacher attaches a small mass to the tine of a tuning fork. What effect will this have on the frequency of the fork's vibrations? Justify your prediction.

3. **Observe.** Listen to the sound of the tuning fork with the added mass. Do you notice any difference?

4. **Observe.** Your teacher now strikes the two forks together so the two waves interfere. Describe what you hear.

5. **Observe.** Now we move the small mass a bit higher up the tine of the tuning fork. Describe what you hear.

6. **Speculate.** The pulsing pattern is telling us something about the difference in the frequencies of each fork. Which fork has the higher frequency? How did moving the mass change the frequency?

7. **Observe.** Measure the frequency of the pulsing pattern.

Two sound waves with slightly different frequencies interfere and produce *beats*. Our ears perceive this as a throbbing or pulsing sound. The frequency of the throbbing sound is called the *beat frequency* which can be found by taking the absolute value of the difference in the original sound wave frequencies: $f_b = |f_2 - f_1|$. Reminder: the absolute value signs always make f_b a positive value. This throbbing sound is often heard when musical instruments are slightly out of tune.

8. **Calculate.** What is the frequency of the tuning fork with the mass on it?

SPH3U: Waves and Sound Homework

1. **Calculate.** A deep, dark well has vertical sides and water at the bottom. You clap your hand and hear the sound wave from your clap return 0.42 s later. The air in the well is cool, with a temperature of 14°C. How far down in the well is the water surface? (Use a solution sheet for this question)

2. **Calculate and Explain.** Most stringed instruments gradually go flat (frequencies decrease) as the strings lose their tension. Yesterday, you had your guitar A string (440 Hz) properly tuned. Today, you pick up your instrument and play your A string along with a friend who is properly tuned. You are shocked as you hear the pulsing of beats. You notice 3.0 beats per second. What is the frequency of your A string today? Explain your answer.

3. **Calculate and Explain.** Wind instrument players don't have it any easier. The tuning of their instruments will change depending on the temperature of the room. So as the band gets going and the room heats up, their tunings will go sharp (frequencies increase). At the start of band class you and the vibraphone are properly tuned and play a C with a frequency of 523 Hz. Later on, you and the vibraphone play the C again and hear 4 beats per second. The vibraphone remained correctly tuned. What is the frequency of your C? Explain your answer.

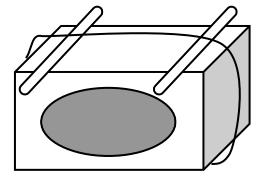
SPH3U: The Vibrating String

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
R 1 2 3 4

One of the most ancient topics in physics is the study of the vibration of strings. The patterns of vibrating strings have fascinated people from Pythagoras all the way to the present day where you may have heard of the theory of subatomic particles known as "String Theory" from the TV show *The Big Bang Theory*.s

A: String Theory

For this investigation you will build your own *sonometer* – a device to help study the vibration of strings. To do this you will need a tissue box, two pens or pencils, and a couple of elastics that can easily fit around the box. Assemble your sonometer according to the diagram. The elastic vibrates in the space between the two pencils. The elastics push on the box periodically which begins to resonate with the elastic. This amplifies the sound.



1. Slide one of the pencils closer to the other. Describe what happens to the pitch of the sound of the string.

2. When the string is one half its original length, describe how the pitch of the original and new sounds compare. If you have a hard time describing, see if there is a violin, guitar, erhu, or zheng player in your group or a nearby one.

3. Set the pencils far apart. Pull on the elastic along the side of the box. What characteristic of the elastic are you changing when you pull on it? Describe what happens to the pitch of the sound?

4. Choose a different elastic and remove the current one on the box. Place the two side by side and describe how they are different.

5. Predict how their pitches will compare.

6. Put both on to the box side by side. Do the sounds agree with your prediction? Offer a reason why or why not.

7. What conclusions can you make about the relationship between frequency and length and between frequency and tension?

B: Frequency and Length – A Cello Lesson

The shorter the vibrating string, the higher the frequency. For a given string and tension we have the relationship: $f_2/f_1 = L_1/L_2$, where f_1 and L_1 are the original frequency and length of the string and $f_2$and L_2 are the new frequency and length. The ratio between two frequencies f_2/f_1 defines a *musical interval*.

The standard cello has its "A" string tuned to the pitch known as A-220, meaning a frequency of 220 Hz. Its four strings vibrate between the nut and the bridge – a distance of 69.0 cm. By placing your fingers on the fingerboard you change the length and frequency of the string.

1. The chart below shows the ratios for some typical musical intervals. According to the ratios, how does the frequency of a note a perfect fifth higher compare with the lower note?

2. Explain how the length of the string should be changed to produce the note 'E'.

3. Calculate the frequency for each new pitch. Always use A-220 as f_1. Calculate the new lengths of the string for each note. Show one sample calculation below for the frequency and finger location of the musical note 'E'.

Musical Interval	f_2 / f_1	Musical Note	f_2	L_2
Major Second	9 / 8	B		
Major Third	5 / 4	C#		
Perfect Fourth	4 / 3	D		
Perfect Fifth	3 / 2	E		
Major Sixth	5 / 3	F#		
Major Seventh	15 / 8	G#		
Perfect Octave	2 / 1	A′		

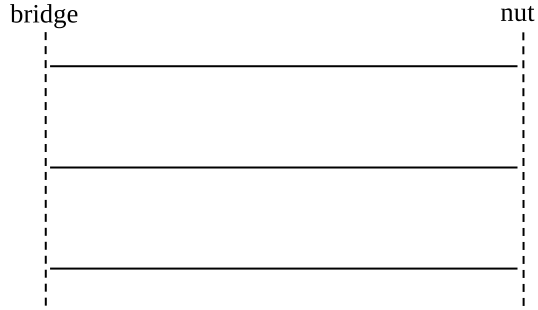
4. Now we will test the results of your calculations. Create a blank fingerboard (strip of paper 69.0 cm long. Your challenge is to mark and label the positions that you should place your fingers along the cello fingerboard to produce each new note. You will slide this paper under the cello's strings and make the sounds!

Sample calculation:

SPH3U: The Vibrating String Homework Name:

When we pluck or bow a string it will vibrate most strongly in its fundamental mode (at its natural frequency). When we study the frequency or length of string vibrations we will always assume it is vibrating in this mode.

1. **Represent.** Show the standing wave pattern for the cello string when we play the low A, the E and the high A. Make sure it is clear which portion of the string is vibrating and which is not.



2. **Calculate.** Use the results from your chart in today's investigation. What is the speed of the waves traveling in the violin string when we play an E?

3. **Calculate.** You are practicing your cello and play an A-220. Then you play a B-flat which is one semi-tone higher. The ratio of the two frequencies is 1.059 / 1. What is the frequency of the B-flat? What is the vibrating length of the string?

4. **Calculate.** An octave is the musical interval between two notes with a frequency ratio of 2/1. A-440 is the standard frequency used to tune modern instruments. What are the frequencies of the A's that are one and two octaves above A-440 and one and two octaves below A-440?

5. **Calculate.** A spring 4.7 m long vibrates with a frequency of 3.7 Hz in its fundamental mode. You hold the spring down so that only a 2.1 m section can vibrate (without changing any other characteristics of the spring). What is the natural frequency of this section?

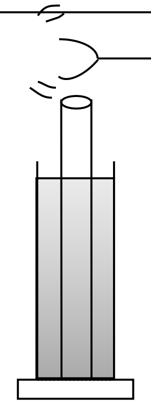
6. **Calculate and Explain.** A 30 cm violin string vibrates in its fundamental mode and produces a concert A pitch of 440 Hz. The temperature of the room is 21^{o}C.
(a)What is the speed of the wave in the violin string?
(b) What is the speed of the wave in the air?

SPH3U: Resonance in Air Columns

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
R 1 2 3 4

A: Standing Waves in an Air Column

You need a large graduated cylinder, a long plastic tube, a metre stick and a tuning fork (512 Hz are best).Fill the cylinder with water until about 5 cm from the top. **Have one group member in charge of making sure it does not tip over during the investigation.**



1. **Observe.** Strike and hold the tuning fork just above the tube. Slowly raise the tube from the bottom until you hear the first resonance – the sound will suddenly become louder. Keep striking the fork so it doesn't become too soft.

2. **Explain.** Why is this situation an example of resonance? What is the driving force? What part do you think is resonating?

3. **Predict.** Emmy says, "I think the plastic tube itself is resonating and producing the loud sound we hear." Marie says, "I think the air inside the tube is resonating and producing the loud sound we hear." Isaac says, "We need to test these two theories!" Your group will set up the air column so you hear the resonance and then have a group member hold the sides of the tube (don't do this yet!) Predict what will happen when the sides are held according to Emmy's theory and Marie's theory.

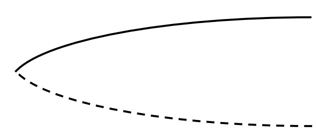
   Emmy:

   Marie:

4. **Test and Evaluate.** Now you may conduct your test and evaluate the two hypotheses you created. Explain.

A standing wave forms when waves travel through a medium, reflect off the ends and interfere with waves travelling in the opposite direction (just like we studied with the springs). Sounds waves travel up and down the air column and reflect off the bottom end (the water surface) and the top end (the opening of the tube). The sound wave behaves differently at the two boundaries of this air column which we call the *boundary conditions*. One boundary condition is the *closed end* (our water surface). Here the air particles cannot be easily displaced because they are pushed up against the water surface. This creates a *displacement node* in the standing wave pattern. At the closed end, most of the wave's energy reflects back up the tube. The other boundary condition is the *open end* (the top of our tube). Here the air particles are easily displaced (no hard surface blocks them) and a *displacement anti-node* is created. At an open end, some of the wave's energy is reflected back into the tube (helping to create the standing wave) and some is transmitted into the open air around it, producing the sound wave that we hear.

5. **Represent.** To illustrate a standing wave, we can draw a standing wave diagram for the air column that shows the nodes and anti-nodes. This first example shows the fundamental mode (first harmonic) – the simplest standing wave pattern for your air column. Label the nodes and antinodes on this diagram.



6. **Explain.** We don't see a complete wavelength (or cycle) in this diagram. What fraction of the wavelength of this sound wave fits in your air column?

B: Finding Resonant Lengths

How does the length of an open-closed air column affect resonance?

1. **Explain.** Why is your air column called an *open-closed* air column?

2. **Observe.** Lift your tube up and down through a wide range of lengths. Does resonance occur at only one length? How many difference resonances (resonant lengths) do you notice?

3. **Reason.** When changing to another resonant length does the wavelength (or frequency) of the sound change? How can you tell?

4. **Observe and Represent.** Make sure you have found the shortest air column that produces a resonance. This is called the *first resonant length*. Use a ruler to measure the length of air column. Draw the standing wave diagram for the particle displacements. How many wavelengths long is this pattern? Complete row 1 of the chart.

Resonant Length	L (cm)	L (λ)	Standing Wave Diagram
1			
2			

5. **Observe.** Continue the experiment by looking for the *second resonant length*. This is the next length that will hold a standing wave pattern based on the frequency of the fork. Measure the length of this air and complete row 2 of the chart. Double check: if your diagrams are correct, the wavelengths in each should look the same.

6. **Summarize.** When an air column is increased in length from one resonant length to the next, what fraction of a wavelength is added to the standing wave pattern? (This is true for all standing wave patterns!)

C: Finding a Resonant Frequency

For this investigation you will use a ***large tube*** and a ***signal generator app*** with a speaker set up at the front of the class. The tube has two open ends. To produce resonance this time, we won't change the length of the air column. Instead, we will change the frequency of the sound and find the frequencies that create a standing wave in the air column (like in the shower!)

An *open-open air column* has the boundary condition of two open ends. When resonance occurs and a standing wave is created in this air column, there is an antinode at each of the open ends.

1. **Represent.** The simplest standing wave pattern that can form in an open air column with a fixed length has one node in the centre and one antinode at each end. Draw this standing wave in the chart.

2. **Reason.** Measure the length of the tube. What fraction of a wavelength is in the air column? Complete the first row of the chart.

Harmonic	L (cm)	L = __λ	Standing Wave Diagram
First			
Second			

3. **Predict.** What is the frequency of the first harmonic? (You will need to make one more measurement to make this prediction.)

4. **Represent.** The second harmonic will have an additional node in the standing wave pattern. Complete the second row of the chart. Doubler check: are the lengths of your two standing wave diagrams the same?

5. **Reason.** Will the frequency of the second harmonic be higher or lower than the first? Explain.

6. **Predict.** What is the frequency of the second harmonic?

7. **Predict.** Quickly predict a few more harmonics. Try it!

8. **Test.** Determine the resonance frequencies from the signal generator. How do these compare with your two predictions?

9. **Predict.** The air column of most wind instruments is open-open. Take the length measurements for a particular note on the wind instrument your teacher has. Draw a standing wave diagram. Calculate the frequency of the first harmonic.

10. **Test.** Use the frequency analyzer to find the frequency of the instrument. How does this compare with your prediction?

SPH3U: Resonance in Air Columns Homework Name:

Complete these questions on your solution sheets. For B: Physics Representations, draw any wave diagram or helpful graphs of the waves. For C: Word Representation, describe the wave patterns or particle motion.

1. A deep, dark well with vertical sides and water at the bottom resonates at 7.00 Hz and at no lower frequency. (The air-filled portion of the well acts as a tube with one end closed and one open end.) The air in the well is cool, with a temperature of 14ºC. How far down in the well is the water surface?

2. A clarinet behaves as an open-closed column of air with the open end at the bell and the closed end at the reed. Claudia blows very gently – just enough to play a low A with a frequency of 220 Hz. She then blows harder (overblows) using the same fingering and produces the next higher note (the next mode). What is the frequency of the higher note? Can you determine its pitch? (Consult the violin page!)

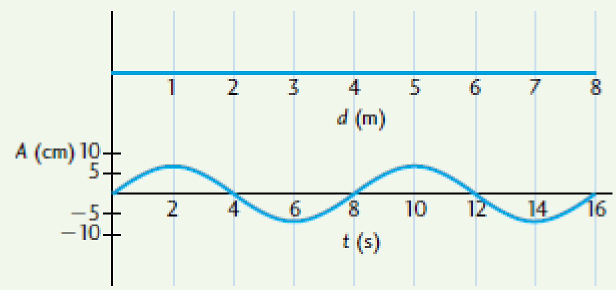
3. The air column of your steamy shower (26ºC) is closed-closed since the sound will reflect off two solid walls at the front and back of the shower. The distance between the two walls is 1.50 m. Draw a standing wave diagram. What are the first two resonant frequencies?

Waves and Sound problems from Concepts and Connections (Irwin) p473

13.1 Introduction to Wave Theory*

23. Use Fig. 13.42 to find
a) the wavelength.
b) the period.
c) the amplitude.
d) the peak-to-peak value (crest to trough).
e) the frequency.

Fig. 13.42 For this problem, note that there are two different scales used (d(m) and t(s)).



24. A tuning fork's tines vibrate 250 times in 2.0 s. Find
a) the frequency of vibration.
b) the period of vibration.

25. There are six classes in one day. If all the classes take 6.5 hours each day, find the
a) frequency of the classes occurring each day.
b) period of the classes.

26. The frequency of a note is 440 Hz. Find the wavelength of the sound given that the speed of sound is
a) 332 m/s. **b)** 350 m/s. **c)** 1225 km/h.

27. The frequency of a tuning fork is 1000 Hz. If the wavelength is 35 cm, find the speed of sound in
a) m/s. **b)** km/h.

28. Gravity waves are still being searched for by astrophysicists. These waves travel at the speed of light ($c = 3.0 \times 10^8$ m/s). If the expected frequency is about 1600 Hz and the size of a football field is 250 m, how many football fields long is the wavelength of a gravity wave?

29. If $\frac{\lambda}{4}$ is 0.85 m and the frequency is 125 Hz, find
a) the wavelength.
b) the period of the wave.
c) the velocity of the wave.

30. Find the period and velocity for the following frequencies if the wavelength is 0.50 m:
a) 0.30 Hz **b)** 400 s^{-1}
c) 30 cycles/s **d)** 5.0 kHz
e) 102.1 MHz

31. Find the frequency and velocity given that the wavelength is 75 cm for the following periods:
a) 0.020 s **b)** 15.0 ms
c) 2.0 min **d)** 0.6 h

32. You are shouting in a monotone voice with a frequency of 440 Hz. Your friend is 300 m away. If the speed of sound is 344 m/s, how many wavelengths occur between you and your friend?

13.2 Transmission and Speed of Sound

35. Calculate the speed of sound in air for the following temperatures:
a) 0°C **b)** 25°C **c)** 30°C **d)** -15°C

36. What is the wavelength of the sound produced by a bat if the frequency of the sound is 90 kHz on a night when the air temperature is 22°C?

37. How far away is a storm if you hear the sound of thunder 7.0s after the lightning flash on a day when the air temperature is 31°C?

38. Determine the depth of water is an echo using sonar returns in 870 ms and the speed of sound in water is 5300 km/h.

39. If it takes 0.8 s for your voice to be heard at a distance of 272 m, what is the temperature of the air? [13°]

41. The air temperature is 20°C. You are swimming underwater when you hear a boat noise. Then, 3.5 s later, you hear a crash. If the speed of sound in water is 1450 m/s, how long after the crash does your friend on the dock beside you hear the crash? [d = 5100 m, t = 14.8 s]

45. Calculate the Mach number for sound, given the temperature and the speed:

(a) 332 m/s at 30°C [0.95]
(b) 340 m/s at -10°C [1.04]
(c) 6000 km/h at 13°C [4.90]
(d) 6000 km/h at -13°C [5.14]

46. How far has a plane travelled from the point at which you hear the sound of a sonic boom if the plane is travelling at Mach 2.2 at an altitude of 8000 m and the average air temperature for the sound is 15°C? It took 3.40 s to hear the sonic boom. [2550 m]

13.4 Sound Intensity

49. Given a sound intensity of 6.0 = 10^{-6} W/m2, find the intensity at the following distances from the source:
a) The distance from the source doubles.
b) The distance from the source quadruples.
c) The distance from the source is halved.
d) The distance from the source decreases by a third.

51. If the surface area that sound travels through is 5.5 m^2 and the source produces a sound power of 3.0 x 10^{-3} W, find the intensity of the sound at the surface.

56. Compare the sound intensity of the threshold of pain (120 dB) to
a) normal conversation (60 dB)?
b) a whisper (20 dB)?
c) a rock concert (110 dB)?
d) 30 m from a freight train (75 dB)?

57. At one point in the room, the sound intensity is 3.5 x 10^{-6} W/m^2. If you move twice the distance away, find
a) the sound intensity at the new distance.
b) the decibel difference between the intensities.

60. A rock concert produces sounds at 120 dB, measured 2.0 m away. How far back should you be in order to listen to the music at 100 dB?

13.5 Doppler Effect

64. A siren emits a sound at 1700 Hz. Assume a speed of sound of 332 m/s. What frequency would a stationary observer hear if the car with the siren is travelling at

a) 25 m/s toward the observer?
b) 25 m/s away from the observer?
c) 140 km/h toward the observer?

65. Repeat Problem 64, assuming an air temperature of 30°C.

66. How fast is a car moving and in what direction if the frequency of its horn drops from 900 Hz to 875 Hz, as heard by a stationary listener? The air temperature is 0°C.

67. As a racing car zooms by you, its pitch decreases by 20%. If the speed of sound is 345 m/s, how fast is the car travelling?

68. The sound of a racing car has its pitch decrease by 10%. If the temperature of the air is 22°C, how fast is the car travelling?

69. Two people hear the 1700 Hz siren of an ambulance. One person is in front and the other person is behind the ambulance. If the ambulance is travelling at 120 km/h, what is the difference in frequencies heard by the two people? Assume the speed of sound to be 333 m/s.

ANSWERS

24. a) 125 Hz **b)** 0.008 s
25. a) 0.92 hr^{-1} **b)** 1.08 hr
26. a) 0.75 m **b)** 0.80 m **c)** 0.77 m
27. a) 350 m/s **b)** 1260 km/h
29. a) 3.4 m **b)** 0.008 s **c)** 425 m/s
30. a) 0.15 m/s **b)** 200 m/s **c)** 15 m/s **d)** 2500 m/s **e)** 5.1 x 10^7 m/s
31. a) v = 38 m/s **b)** v = 50 m/s **c)** v = 0.0063 m/s **d)** v = 3.5 x 10^{-4} m/s
32. λ = 0.782 m 383 wavelengths
56. a) 106 **b)** 1010 **c)** 10 **d)** 3.2 x 10^4
57. a) 8.75 x 10^{-7} w/m2 **b)** 6 Db
60. 20 m back
64. a) 1840 Hz **b)** 1580 Hz **c)** 1930 Hz
65. a) 1830 Hz **b)** 1590 Hz **c)** 1910 Hz
66. 9.49 m/s
67. 86 m/s
68. 38 m/s

69. 346 Hz

14.6 Acoustic Resonance and Musical Instruments

19. An air column that is open at both ends has a distance of 24.0 cm from one resonant length to another. What is the wavelength of sound that is in resonance with this tube? How would the wavelength be affected if the tube was closed at one end?

20. Water is slowly drained out of a tube until the air column is 8.0 cm long. A loud sound is then heard.
a) What is the wavelength of the sound that is produced by resonance?
b) How long would the tube have to be for the same note to resonate at the third resonant length?

21. A tuning fork vibrating with a frequency of 950 Hz is held near the end of an open air column that has been adjusted to its first resonant length at 25.0ºC.
a) What is the speed of sound in the room?
b) What is the wavelength of the sound produced?
c) How long is the tube in centimetres?

22. A 1024 Hz tuning fork is held up to a closed air column (closed at one end and open at the other) at 30.0ºC. What is the minimum length of an air column that would resonate with this frequency?

23. Organ pipes, open at one end, resonate best at their first resonant length. Two pipes have length 23.0 cm and 30.0 cm respectively.
a) What is the wavelength of the sound emitted by each pipe?
b) What are the respective frequencies if the speed of sound is 341 m/s?
c) What is the air temperature in this church?

24. One of the tubes in Pan's flute measures 10 cm from one open end to the other. The air temperature is 20.0ºC.
a) What is the fundamental wavelength of the note that is heard?
b) What is the corresponding frequency?

25. A tuning fork was sounded over an adjustable closed air column. It was found that the difference between the second and fifth resonant length was 90.0 cm. What was the frequency of the tuning fork if the experiment was done in a lab with air temperature 25.0ºC?

26. Hollow tube chimes are made of metal and are open at each end. These columns resonate best at their third resonant length. One chime is 2.5 m long and the air temperature is 25.0ºC.
a) What is the speed of sound?
b) What is the wavelength of the sound produced?
c) What is the frequency of the sound that is heard

ANSWERS:
19. 0.48 m, decrease base fundamental frequency
20. 0.40 m
21. a) 347 m/s **b)** 0.365 m **c)** 18.3 cm
22. 8.55 cm
23. a) 92.0 cm, 120 cm **b)** 371 Hz, 284 Hz **c)** 15°C
24. a) 20 cm **b)** 1.7×10^3 Hz
25. 578 Hz
26. a) 347 m/s **b)** 1.7 m **c)** 2.0×10^2 Hz

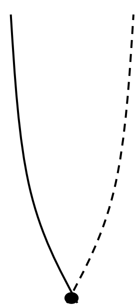
SPH3U: Harmonics Review   Name:

1. A string is stretched out and fixed at both ends. The different standing wave patterns that can form in the string are called the harmonics. Complete the chart below for the different standing wave patterns for string fixed at both ends.

Harmonic	Sketch	# of λ	Frequency Compared to f_o
1^{st}			$f = 1f_o$

2. In columns of air, the pattern of harmonics depends on the type of air column. Complete the chart below.

Open-Closed Columns

1^{st} harmonic	2^{nd} harmonic	3^{rd} harmonic
# of λ = f = **$1 f_o$** 	# of λ = f =	# of λ = f =

Closed-Closed Columns

1^{st} harmonic	2^{nd} harmonic	3^{rd} harmonic
# of λ = f = **$1 f_o$**	# of λ = f =	# of λ = f =

SPH3U: Resonance in Air Columns Homework Name:

1. A deep, dark well with vertical sides and water at the bottom resonates at 7.00 Hz and at no lower frequency. (The air-filled portion of the well acts as a tube with one end closed and one open end.) The air in the well is cool, with a temperature of 14ºC. How far down in the well is the water surface?

2. A clarinet behaves as an open-closed column of air with the open end at the bell and the closed end at the reed. Claudia blows very gently – just enough to play a low A with a frequency of 220 Hz. She then blows harder (overblows) using the same fingering and produces the next higher note (the next mode). What is the frequency of the higher note?

3. The air column of your steamy shower (26ºC) is closed-closed since the sound will reflect off two solid walls at the front and back of the shower. The distance between the two walls is 1.50 m. Draw a standing wave diagram. What are the first two resonant frequencies?

SPH3U: Waves and Sound Problem Set Name:

Communication Rubric	**< Level 1** **3.0 4.0**	**Level 1** **5.2 5.5 5.8**	**Level 2** **6.2 6.5 6.8**	**Level 3** **7.2 7.5 7.8**	**Level 4** **8.4 8.9 9.5 10**
communication of information / solutions with		... limited clarity and precision	... moderate clarity and precision	... considerable clarity and precision	... a high degree of clarity and precision
uses of scientific terminology and SI units with		... limited accuracy and effectiveness	... some accuracy and effectiveness	... considerable accuracy and effectiveness	... a high degree of accuracy and effectiveness

Answer one question from each category with complete solutions. *A complete solution must include a diagram, known quantities, numbered steps to solve the problem and a concluding statement with your answer rounded properly. For intermediate steps, keep one extra digit and truncate.*

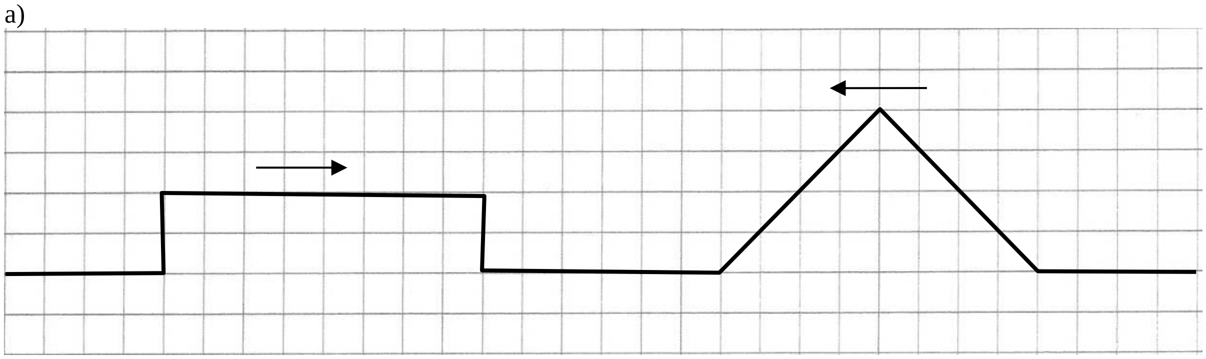
Wave Theory

1) The distance between 2 crests of a wave on a lake is 0.740m and it has a period of 0.380s. Find the speed and frequency of the wave.

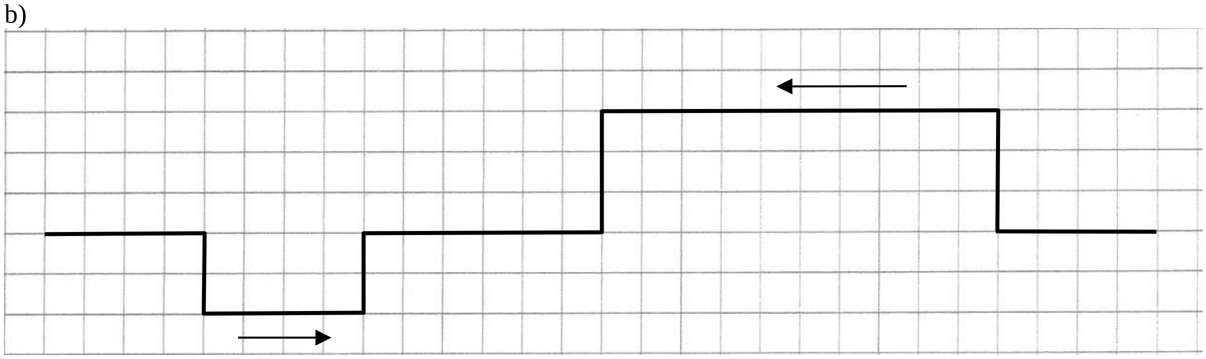
Principle of Superposition

2) Use the principle of superposition to determine the resulting pulse when the pulses shown in **below** are superimposed on each other. (The point of overlap should be at the horizontal midpoints of the pulses.)

a)



b)



Standing Wave Patterns

3) The distance between the second and fifth nodes in a standing wave is 59 cm. What is the wavelength of the waves? What is the speed of the waves if the source has a frequency of 25 Hz?
4) Draw a scale diagram of a standing wave pattern on an 8.0-m rope with four antinodes between the ends. What is the wavelength of the waves that produced the pattern?

Properties of Sound

5) Compare the speed of sound on a summer's day (T=25.0°C) to a cold winter's day (T=-25.0°C).
6) On a cloudy day when the temperature is T=15°C, a student standing near a brick wall claps her hands and hears the echo 0.250 s later. How far from the wall was she?
7) A police officer with an exceptionally good ear hears an approaching motorcycle at a frequency of 195Hz. After the motorcycle passes he hears a frequency of 147 Hz. How fast was the bike moving on this warm summer's 20°C day (use v_{sound}=344 m/s)?
8) Find the speed in km/h of the SR-71 Blackbird if it travels at Mach 3.00 when the air temperature is 25.0°C.
9) Compare the sound intensity of a normal conversation (60dB) to the sound of Niagara falls (80dB).

Acoustical Resonance

10) What lengths of an air column will produce resonance from a 128 Hz tuning fork at 20°C if
    a) it is open on both ends?
    b) it is closed at one end?

11) Draw diagrams to show the first three modes of resonance in the following instruments. The find the frequencies of these modes if v_{sound}=344 m/s. (*oerb*)
    a) A clarinet 75 cm long that functions acoustically like a closed air column
    b) An organ pipe open at both ends that is 4.8 m long
    c) A guitar string 1.3 m long with a wave speed of 66 m/s

12) A closed air column is 60.0 cm long. Calculate the frequency of forks that will cause resonance at room temperature, 20º C, at
    a) the first resonant length
    b) the third resonant length

13) The A string of a violin is a little too tightly stretched. Four beats per second are heard when the string is sounded with an A-440 tuning fork. What is the period of the violin string oscillation?

14) A 30 cm violin string vibrates in its fundamental mode and produces a concert A pitch of 440 Hz. What is the speed of the wave in the violin string?

15) John times a pulse that travels along a 10.0 m wire in 0.85 s. What are the three lowest frequencies for standing waves in this wire?

16) A large wood block of a xylophone vibrates with a standing wave pattern that is similar to an open air column (an antinode at each end and two nodes in between). The block is mounted on the steel frame at the nodes. The hard wood used for the blocks has a wave speed of 3600 m/s. How far apart are the two nodes for an E (2640 Hz)?

1) *v=1.95 m/s   f=2.63 Hz*
3) *λ=39 cm; v=9.8 m/s*
4) λ=4.0 m
5) $v_{sound@+25°C}$=347 m/s
   $v_{sound@-25°C}$=317 m/s
6) *d=42.6 m*
7) v_{source}=48.3 m/s
8) $v_p=3.75\times10^3$ *km/h*
9) *Niagara falls is 100x louder*
10a) $L_1=1.34$ m $L_2=2.68$ m $L_3=4.02$ m
10b) $L_1=0.67$ m $L_3=2.01$ m $L_5=3.36$ m
11a) f_1=115 hz, f_3=344Hz, f_5= 574 Hz
11b) f_1=35.8 Hz, f_2=71.6 Hz f_3=107 Hz
11c) f_1=51hz, f_2=101.5 Hz, f_3=152 Hz
12a) f=143Hz
12b) f=425Hz
13) T=2.25×10^{-3}s
14) v=264 m/s
15) f_1=0.59Hz f_2=1.17 Hz f_3=1.75 Hz
16) distance = 0.68 m