Gr. 11 Physics Waves and Sound

This chart contains a complete list of the lessons and homework for Gr. 11 Physics. Please complete all the worksheets and problems listed under "Homework" before the next class. A set of optional online resources, lessons and videos is also listed under "Homework" and can easily be accessed through the links on the Syllabus found on the course webpage. You may want to bookmark or download the syllabus for frequent use.

Waves and Sound

1	Good Vibrations	Periodic motion, types of vibrations, frequency, period, amplitude, displacement, phase	E-Book: The Physics of Music Read: *Vibrations*, pg. 196-198 Problems: pg. 198 #2-6, pg. 202 #4 Handbook: *Good Vibrations Homework pg.4*
2	Making Waves	Medium, pulses, crest, trough, energy, transverse waves, fixed/free-end reflections, graphing waves	Read: *Transverse Waves*, pg. 205, 206, *Transmission and Reflection* pg. 212-213 Problems: pg. 207 #1,2, pg. 208 #3,4 pg. 213 #1,2 Handbook: *Making Waves Homework pg.8* Lesson: Intro to Waves Video: Types of Waves Simulation: Transverse Waves
3	Interference	Superposition principle, constructive and destructive interference Two Crests Video Crest + Trough Video Crest + Trough Video	Read: *Interference of Waves*, pg. 219-220 Problems: pg. 221 #1,2, pg. 222 #1,2 Handbook: *Interference Homework pg.11* Video: Two Pulses Interfering Video: Wave Interference
4	The Speed of Waves	Wave speed, Universal wave equation, dependence on medium	Read: Universal Wave Equation pg. 209-211 Problems: pg. 211 #1, #1-5 Handbook: *Speed of Waves Homework pg.12* Video: T, F, and v
5	Standing Waves	Standing waves, nodes, antinodes, modes, resonance, resonant frequency	Read: *Standing Waves*, pg. 226-230 Problems: pg. 229 #1-3, pg. 230 #1,3 Handbook: *Standing Waves Homework pg.17* Lesson: Standing Waves Video: Standing Waves Video: Shatter Glass Video: Shatter Glass
6	Resonance		Read: *Mechanical Resonance*, pg. 223 Handbook: *Resonance Homework pg.18* Video: Resonance
7	Sound Waves	Longitudinal waves, sound waves, medium, particle displacement, representing sound waves	Read: *Longitudinal Waves*, pg. 206 Problems: pg. 207 #3 Handbook: *Sound Waves Homework pg. 24* Simulation: Sound Waves
8	The Propagation of Sound	Speed of sound	Read: *Speed of Sound*, pg. 243 Problems: pg. 243 #1,3, pg. 246 #1,2,5 Handbook: *Propagation of Sound Homework pg. 26* Video: Transverse and Longitudinal Waves
9	The Interference of Sound	Interference of sound waves, beat frequency, Loudness, pitch, intensity, timbre, waveform	Handbook: *Interference of Sound Homework pg.29* Read: *The Interference of Sound*, pg.260-266 Problems: pg. 266 #1,2, pg. 267 #5,6 Read: *Music and Scales*, pg. 278-279 Read: *What is Sound*, pg. 238 Read: *Intensity of Sound*, pg. 247-248 Read: *Modes of Vibration* pg. 284-285 Simulation: Beats,
10	The Vibrating String	Frequency dependence on length, tension, harmonic series	Handbook: *Vibrating String Homework pg.30* Read: *Vibrating Strings*, pg. 281-282 Problems: pg. 283 #3, 2,3, pg. 280 #3
11	Resonance in Air Columns	Open and closed air columns, resonant length, resonant frequency	Read: *Resonance in Air Columns*, pg. 287-292 Problems: pg. 290 #1-4, pg. 292 #1-7 Lesson: Air Columns Activity: Acoustical Resonance
12	Musical Instrument Presentations		Handbook: *Harmonics Review pg.37* Review Problems: pg. 234 #2,3,6-8,10,13-16,20, pg. 274 #6-8,10,14,20,21,23,24, pg. 312 #1,2,4,8a,13-16 Lesson: All About Waves Review: Waves Review: Sound and Music
13	Problem Solving / Review		
14	Test		

SPH3U: Good Vibrations

Recorder: _____
Manager: _____
Speaker: _____
0 1 2 3 4 5

A: Oscillations and Amplitudes

You will need: a retort stand, a C-clamp, a test-tube clamp, a metal spring, a small object (~ 200 g), a ruler and a stopwatch. Hang the spring from the test-tube clamp on the retort stand. Secure the stand firmly using the C-clamp. Hang your object from the spring.

1. Give the object a small downwards pull and release it (gentle!). Describe the motion of the object. What is different about this motion compared to other motions we have studied in Gr. 11 physics?

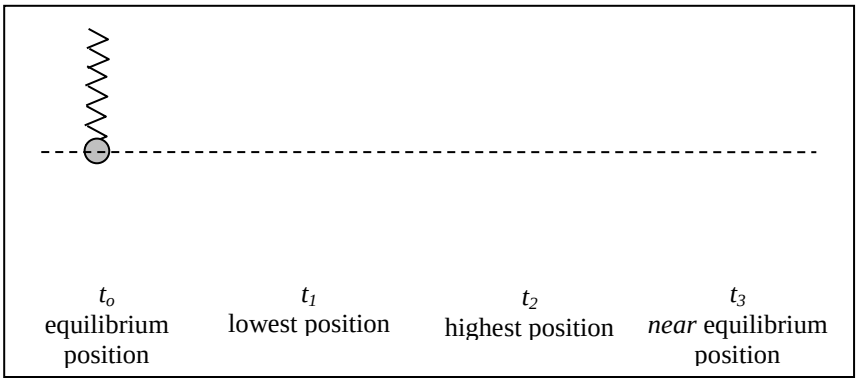
We say that an object moving this way is vibrating or better, *oscillating*. Periodic or oscillatory motion is motion that repeats itself in a regular cycle or pattern. The displacement of the object is measured relative to it *equilibrium position*, which is the position the object would have if it was not in motion.

2. Measure how high above and below the equilibrium position the object oscillates (at least initially). How do these compare? With an ideal spring, these values would remain constant.

The largest displacement of the object from the equilibrium position is the *amplitude* of its oscillatory motion.

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

4. Draw a vector for each moment in time carefully showing the object's <u>displacement</u> from the equilibrium position.



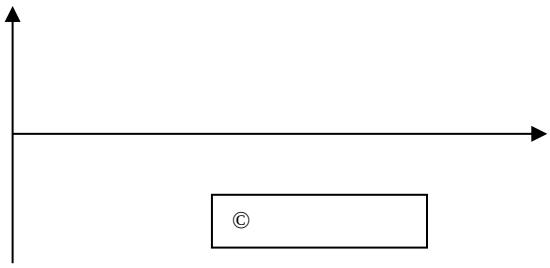
B: Cycles and Periods

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 called the *period* (T).

1. A student wants to time the period of your object's oscillation. He suggests, "I think we should start the timer when the object is at the equilibrium position, watch it go down to its lowest position, then back up to the equilibrium position and stop the timer." Do you agree or disagree? Explain.

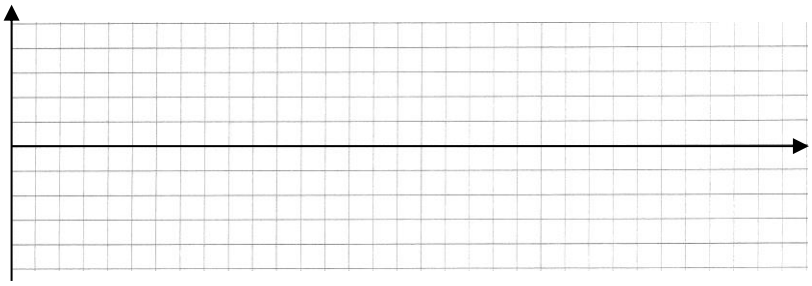
2. Measure the period of your object's oscillations. Explain what a good technique would be to get a very reliable result.

3. On a graph of displacement vs. time, plot five points that correspond to (a) the highest position, (b) the equilibrium position, (c) the lowest position, (d) the equilibrium position, and finally back to (e) the highest position. How do you think these points will each be separated in time? Interpolate what you think the rest of the graph *between* these points might look like.



4. Use the motion detector set up at the front to plot the position-time graph for the oscillating object. **Neatly** sketch the result for a number of periods of time.

5. Choose two points on the graph at different positions. Use horizontal arrows to indicate one complete period of motion, starting from each of those points.



6. How many cycles does your object go through in one second of time? You can use your data from question B#2.

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

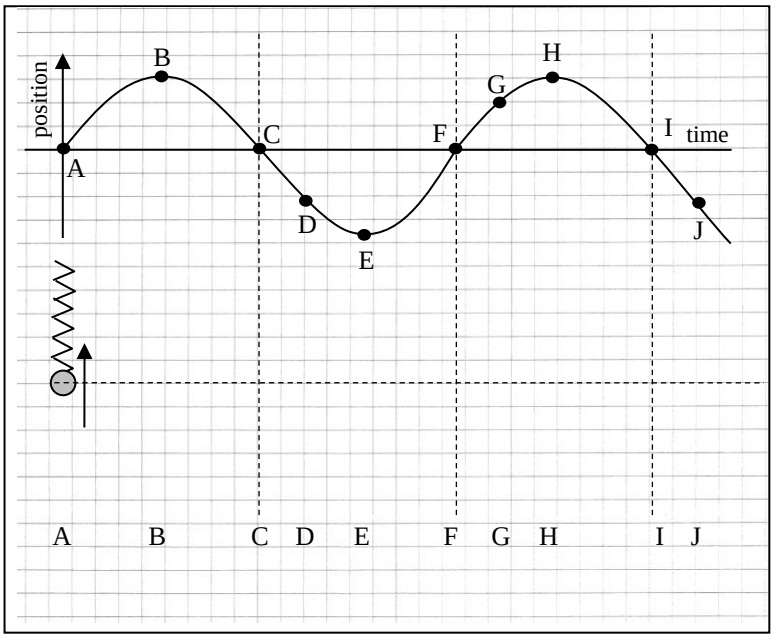
C: Phase

Consider the graph to the right showing the position vs. time for an oscillating object.

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

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

The *phase* of a particle in periodic motion indicates its *state* at one moment in time. The state of the oscillating particle can be completely described by its position and velocity. Phase is most often used for making comparisons. When two states are identical, they have *equal phase* or are *in phase*. Otherwise they are *out of phase*. When two states are half a cycle apart they have *opposite phase*. Note that the expression *out of phase* is commonly used to mean *opposite phase*. Be careful!



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

4. A student says, "I think points A and C have the same phase." Do you agree or disagree? Explain.

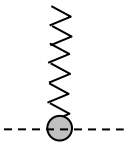
5. Find all the points that have the opposite phase as:
   A:
   B:
   D:

6. Time for some exercise. Your group must demonstrate in phase, in opposite phase and just a bit out of phase. You my only use the people in your group – no equipment! **Show your teacher.**

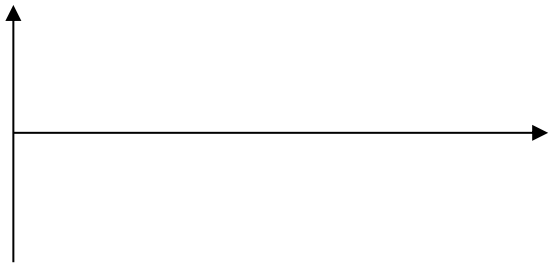
SPH3U: Good Vibrations Homework Name:

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 it 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?

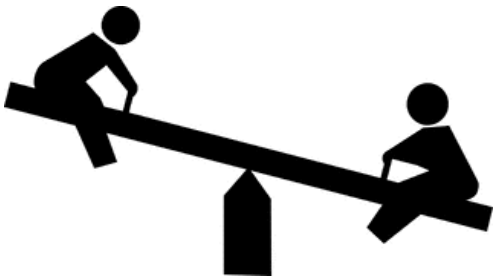
3. **Calculate.** What is the displacement of the ball during one cycle? What is its average velocity?

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

Recorder: _____
Manager: _____
Speaker: _____
0 1 2 3 4 5

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. The *medium*, modeled by our set of particles, is the material substance that the wave travels through, for example: water, air, strings, the earth and so many more!

A: Particle Motion

We will start our investigation by creating pulses in the Wave Machine. Be gentle with the machine – it can be easily damaged. Practice making a pulse which is simply a small, single bump **above** the equilibrium position.

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

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

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

3. Since no particles move horizontally, what does? What is actually travelling back and forth in this medium? Make a guess and move on.

4. (*as a class*) What is a wave?

5. 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.

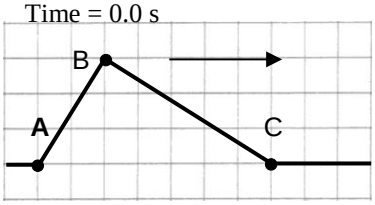
   (d) At what time will the complete pulse have passed through particle C?

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

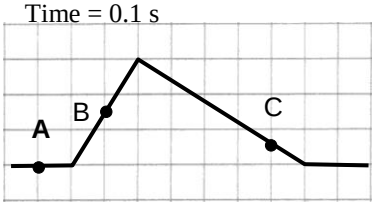
   (f) At what time will particle B return to the rest position?

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

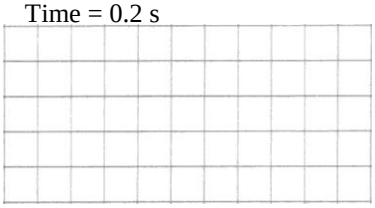
Time = 0.0 s



Time = 0.1 s



Time = 0.2 s

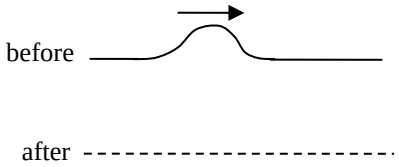


Adapted from *Activity-Based Tutorials,* by Wittmann, M., et al. John Wiley, 2004

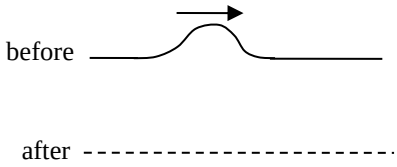
B: Reflection of Pulses and Waves

You may have noticed that the pulses don't just disappear when they reach the end of the medium - they reflect and travel back in the opposite direction.

1. Send a positive pulse (a pulse with positive displacements only = above the equilibrium position) through the medium and carefully observe the shape of the pulse before and after it reflects off the end of the medium. Sketch a diagram. Describe how the shapes compare.



2. Now have someone hold the end of the machine fixed (hold the last rod of the wave machine tightly with two hands). Send a positive pulse through the medium and carefully observe the shape of the pulse before and after it reflects off the end of the medium. Sketch a diagram. Describe how the shapes compare.



How a wave behaves when it reaches the end of the medium depends on the *boundary conditions.* The end of a medium where the particles are free to move is called a *free end*. The end of a medium where particles are held in place is called a *fixed end*.

3. In which situation would you say the pulses or waves reflect *in phase* and in which situation would you say they reflect in *opposite phase*. Explain.

C: The Periodic Wave and Wave Pictures (together)

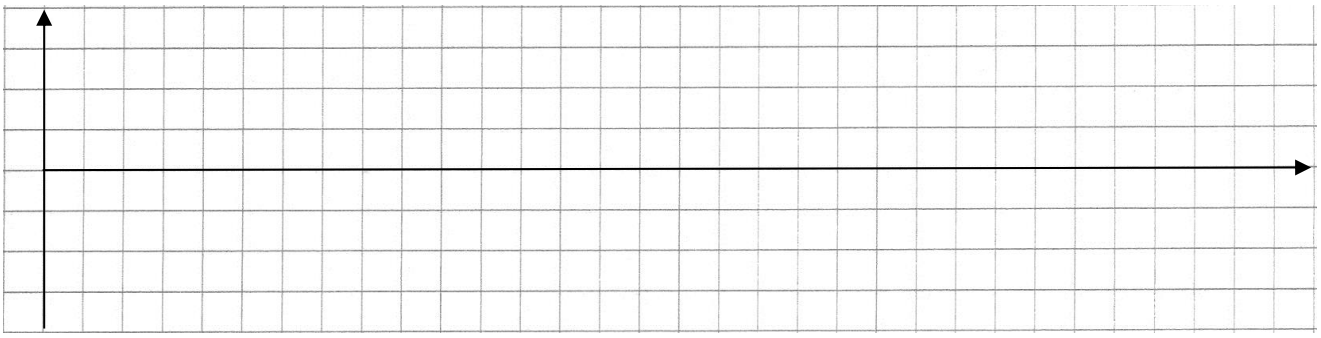
Create a gentle, continuous, periodic wave in the wave machine. You may have to experiment a bit with the frequency of your vibrations so it "settles down" into a nice pattern – make sure you can see a whole wave.

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, it is often convenient to choose two adjacent crests as the nearest points of equal phase.

1. Hold a ruler up to the wave machine and roughly measure its amplitude and wavelength (as if you could freeze the motion of the machine – or take a photo with your phone!)

Imagine taking a photograph of a periodic wave in the wave machine. From such a picture we can create a graph showing the displacement of the different particles in the medium. We will call this the *position picture* of a wave.

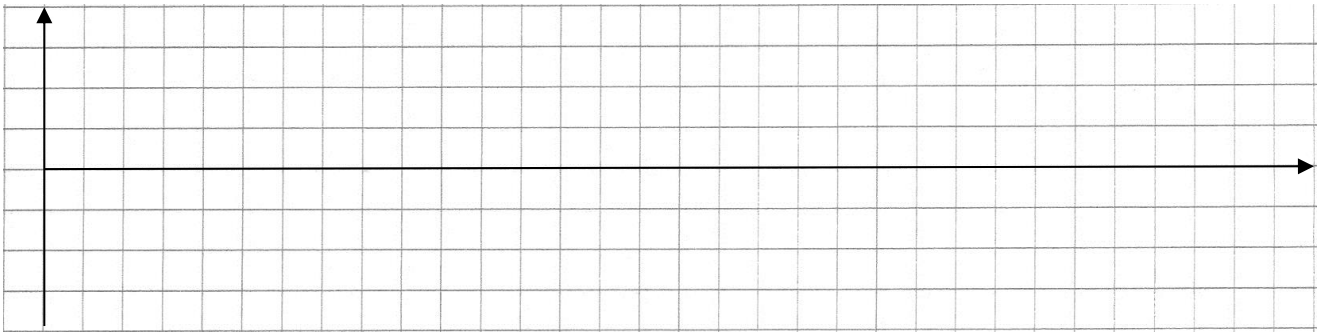
2. Sketch a position picture for your wave. Label your measurements and the axes of the graph.



3. Choose one particle in the medium and measure the period of its oscillations. Describe how you do this and show your results.

Imagine we track the displacement of one particle over time as a periodic wave travels through the medium. We can construct a graph showing the displacement of the particle as a function of time. We will call this the *time picture* of a wave.

4. Draw a time picture for this particle in your wave that completes 3 cycles. Label the amplitude measurement.



5. What does the interval between the two nearest points of equal phase represent in *this* picture? Explain.

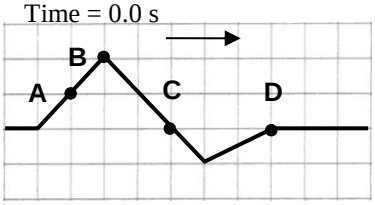
6. Label the period (T) using a horizontal arrow starting from a crest, starting from a trough and starting from a point with a completely different phase.

SPH3U: Making Waves Homework Name:

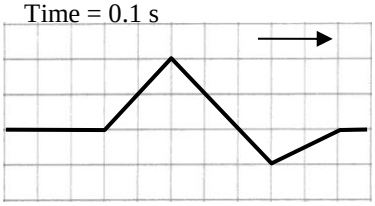
A: Tracking the Particles

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.

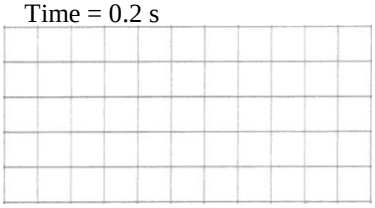
Time = 0.0 s



Time = 0.1 s



Time = 0.2 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 time interval between 0 and 0.1 s?

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

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

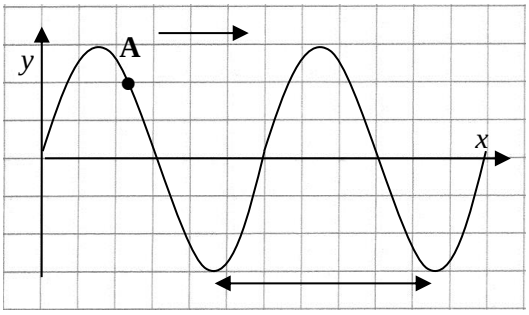
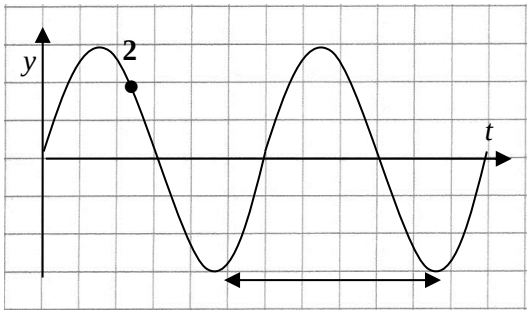
6. **Calculate.** At what time does the pulse completely pass through particle D?

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

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

B: Wave Pictures

Position pictures of a wave and time pictures of a wave can be deceptively similar. Consider a steady wave travelling to the right through a spring.

Position Picture – snapshot of wave	Time Picture – motion of particle A
	

1. **Interpret.** The arrows in each picture indicate an interval. What quantity does each arrow indicate? Explain why.

2. **Interpret.** In the position picture, the point shows the *y*-position of a particle which we will label particle A. In what direction is particle A moving at this moment in time? Explain how you can tell.

3. **Interpret.** In the time picture, point 2 represents the *y*-position of particle A at moment 2. In what direction is particle A moving at this moment in time? Explain how you can tell.

SPH3U: Interference

Recorder: _____
Manager: _____
Speaker: _____
0 1 2 3 4 5

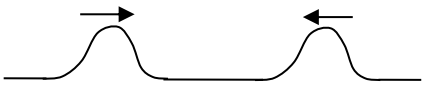
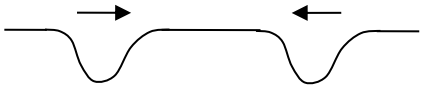
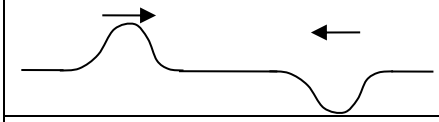
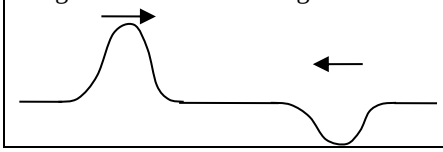
What happens when two waves travel through the same medium and meet?
Let's find out!

A: When Waves Meet

1. What happens to the sound when two people are talking, each producing sound waves, and these waves arrive at the same point in space and overlap? Have you ever been in the middle of such a conversation? What do you hear?

2. What happens when waves or pulses meet? Briefly try sending the pulses shown in the chart below in the wave machine.

3. 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 		

4. Describe what happens when the waves overlap.

5. 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.

6. 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. A sample of the interference process is shown in the first column of diagrams.

1. Study the sample process. Draw an arrow on the first diagram showing the direction in which the pulses are travelling.

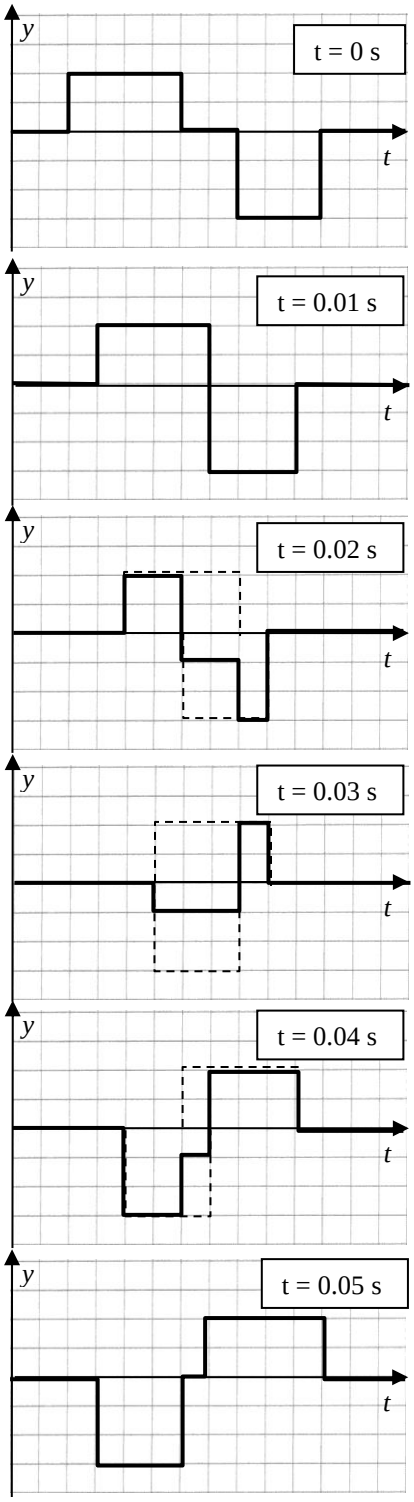
2. At what time do the pulses begin to interfere? At what time will they finish?

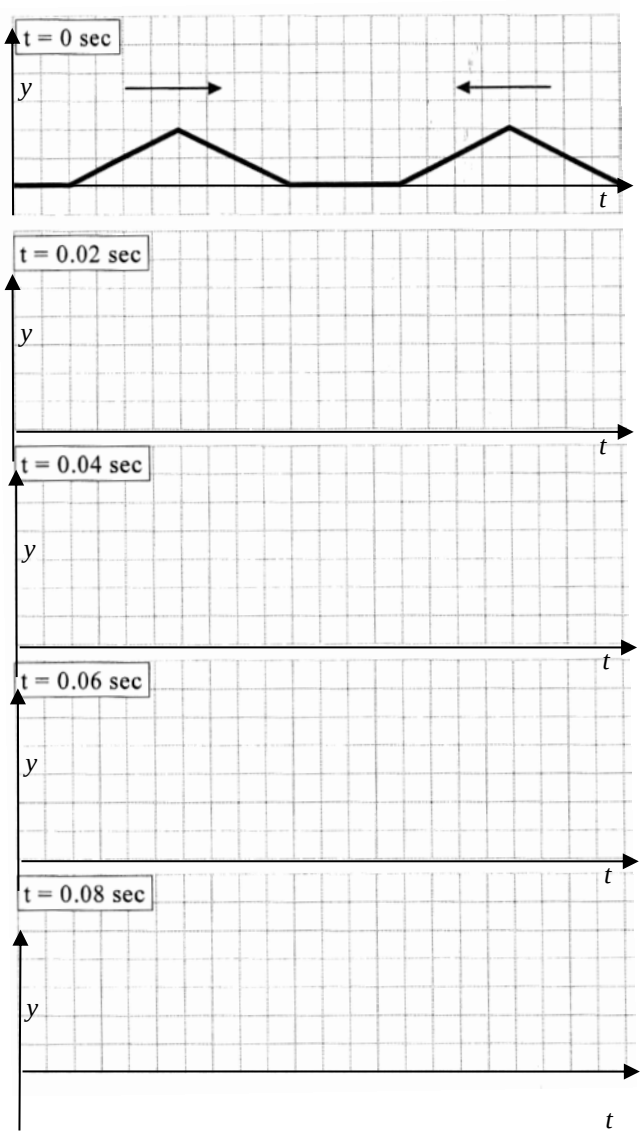
3. At t = 0.02 s, what type of interference occurs?

4. At t = 0.03 s, explain how to find the resulting wave shape.

5. The second column of diagrams is an example for you to try. How many boxes will each pulse travel between diagrams?

6. Complete the set of diagrams. Show the positions of the individual pulses with dashed lines and the resulting wave shape with a solid line.

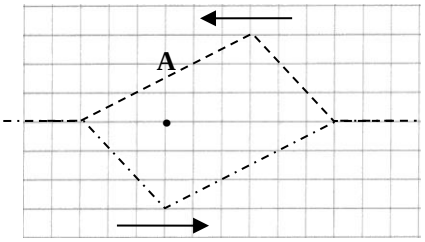




Adapted from *Activity-Based Tutorials,* by Wittmann, M., et al. John Wiley, 2004

SPH3U: Interference Homework Name:

1. The graph to the right shows two wave pulses travelling in opposite directions and interfering.



(a) **Explain.** When these two pulses interfere, do you expect them to completely cancel out (completely interfere destructively)?

(b) **Explain.** Will there be any particles in the medium that have a position of zero when these two waves interfere as shown above?

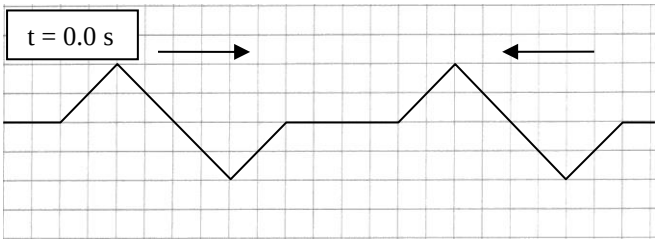
(c) **Calculate and Explain.** Consider point A along the actual medium (point A is showing the position in the medium, not the displacement of the interfering waves). Use the superposition principle to explain how to find the position of that particle in the medium when the two waves interfere.

(d) **Calculate.** Use the superposition principle to find the position of all the particles in the medium when the two waves interfere as shown. Draw this on the graph above.

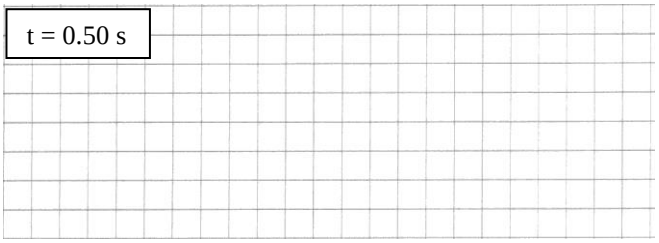
(e) **Calculate and Explain.** The speed of a wave in this medium is 10 grid boxes/second. Starting at the moment shown above, how much time will take for the waves to pass through each other and no longer interfere? Explain your answer.

2. Two waves travel in opposite directions towards one another. Waves in this medium travel with a speed of 8 grid boxes/second.

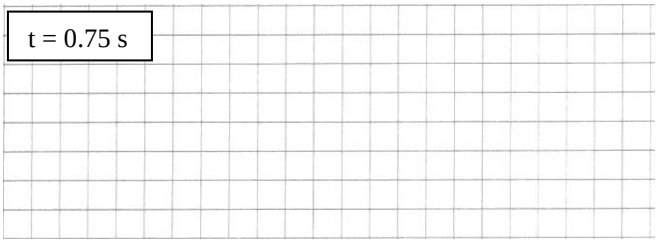
(a) **Calculate**. At what time will the two waves begin to interfere?



(b) **Represent and Explain.** Draw the two separate waves using dashed lines at a time of 0.50 s. Draw the displacement of the medium at this moment in time. What type of interference is occurring?

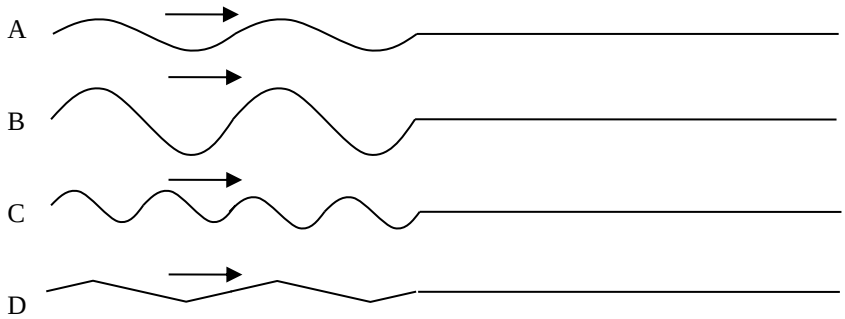


(c) **Represent and Explain.** Draw the two separate waves using dashed lines at a time of 0.75 s. Draw the displacement of the medium at this moment in time. What type of interference is occurring?



SPH3U: Speed 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) **Represent.** Sketch a graph for the wave. Label all the quantities in the description.

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

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

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

   (e) **Calculate and Explain.** What is the wavelength of this wave? Explain how you chose which values to use.

   (f) **Calculate and Explain.** What distance does a particle in the wave move once the wave has passed by?

   (g) **Represent.** Label all the quantities you calculated on your sketch above.

SPH3U: The Speed of Waves

Recorder: _____
Manager: _____
Speaker: _____
0 1 2 3 4 5

A: Ideal Waves and Pulses

Real waves and pulses can be very complex. As a real wave or pulse travels or *propagates* through a medium it may gradually change.

1. (*as a class*) Use the wave machine to create a single pulse. 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. The shape of a pulse also changes – often spreading out. 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.

B: The Speed of a Wave

There are three important characteristics of a pulse that we can easily control: the height (amplitude), the width (wavelength or period) and the shape (waveform – more about this later). We will make pulses with different heights and widths and see how these characteristics affect the speed of the wave.

1. (*as a class*) Make a pulse which will be your "standard" pulse. Get a feel for how quickly it travels back and forth through the medium.
2. We will vary the pulse in a number of different ways and make a rough judgement – does it appear to travel back and forth faster, slower or the same?
3. Draw a conclusion about the pulse or wave speeds in this medium.

Pulse Description	Observations
Large amplitude	
Small amplitude	
Long wavelength	
Short wavelength	
Funny shape	

The speed of a pulse or wave does not depend on the amplitude, shape or period (or frequency). It only depends on the physical properties of the medium, such as density, tension and variety of other factors.

C: Wave Speed in a Coiled Spring (as a class)

We will use a coiled spring to study the motion of ideal wave pulses. **The spring must always remain in contact with the ground! Never let go of the spring while it is stretched! Be sure it does not get tangled up!** Stretch the spring enough so you can clearly see a wave make a complete trip back and forth. We will need a measuring tape and stopwatch.

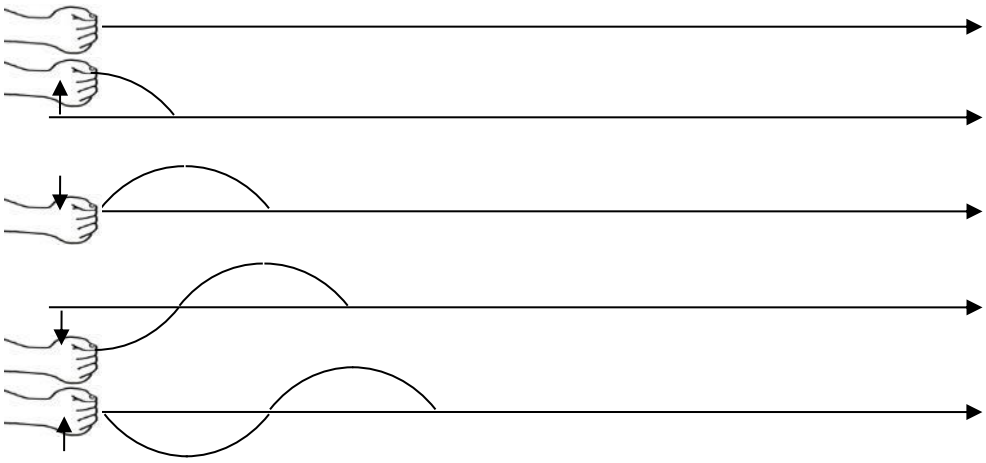
1. There is one characteristic of this medium (the spring) that we can easily change – the tension. Increase the tension and determine the wave speed.
2. Describe roughly how tension affects the wave speed.

Tension	Speed

D: Speed, Wavelength and Frequency

How is the speed of a wave related to its frequency and wavelength? Let's think this through. The diagrams below show your hand which moves up and down with a fixed frequency as it generates a wave.

1. Study the motion of your hand in the diagram. What fraction of a cycle does your hand move through between each picture?



2. What do we call the time interval for the motion of your hand in this diagram?

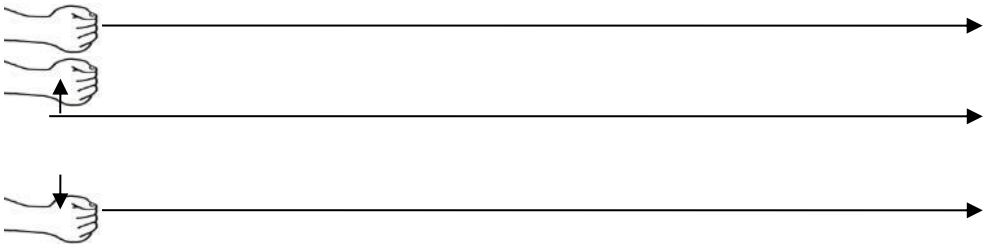
3. What fraction of a wavelength do we see in each diagram? Label these lengths.

4. How far does a wave travel in the time of one period?

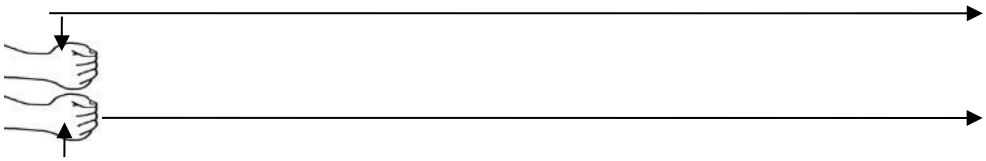
5. How could we find the actual wavelength of this wave if we knew the period (0.5 s) and the wavespeed (4.7 m/s)?

Now you generate another wave, but the time taken by your hand has **doubled**. Nothing else about the situation has changed.

6. How will the frequency of your hand (and the wave) compare with the previous example?



7. How will the wave speed compare with the previous example?



8. How will the distance travelled by the wave during your one cycle of your hand's motion compare with the previous example? Sketch this in the diagrams above. Label your diagrams like the previous example.

9. Describe how frequency affects the size of the wavelength. Be as precise as possible.

The *universal wave equation,* $v = f\lambda$, relates the frequency and wavelength of a wave to the wave speed in a given medium. Note that a change in frequency affects the wavelength and vice versa, but **do not affect the wave speed**. The wave speed depends on the physical properties of the medium only.

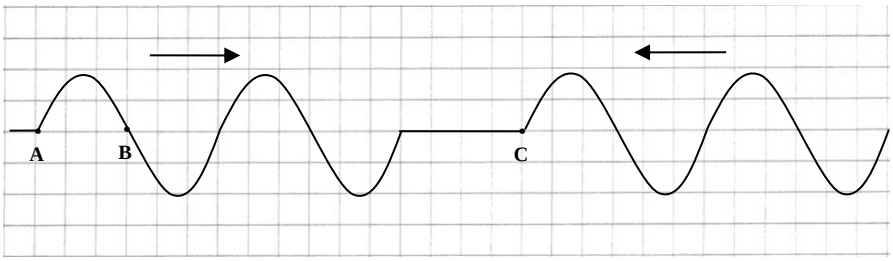
SPH3U: Standing Waves

Recorder: _____
Manager: _____
Speaker: _____
0 1 2 3 4 5

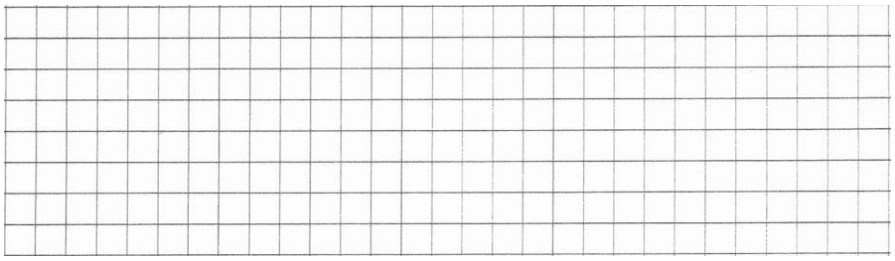
A: When Continuous Waves Interfere

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

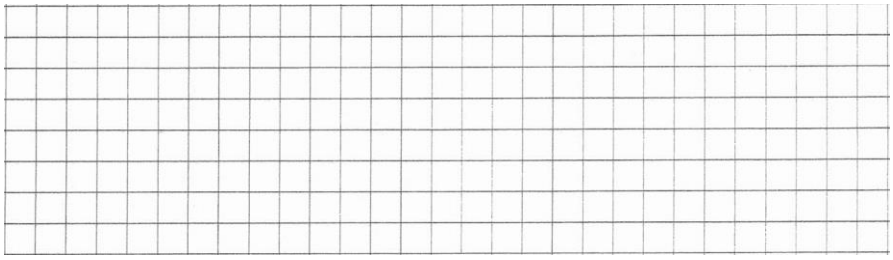
The points A, B, and C are points of constant phase and **travel with the wave**. We will use these to help keep track of the wave.



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. Borrow the transparencies of these waves to help visualize this. 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.

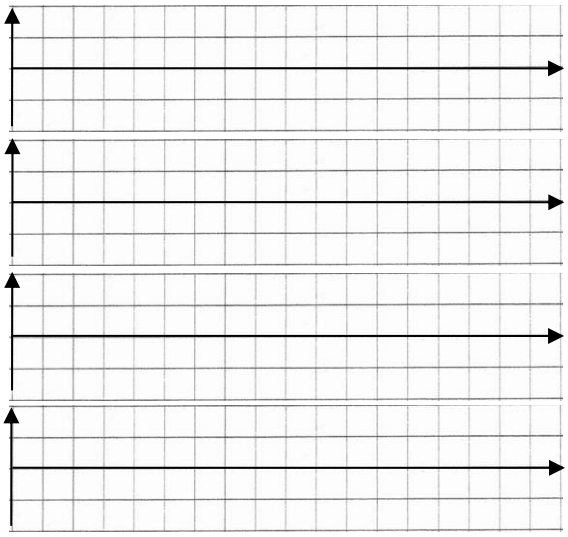


B: Representing Standing Waves

When the interfering process we examined above repeats, a standing wave is created. Your teacher will create a standing wave in a wave machine (or show a video).

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.

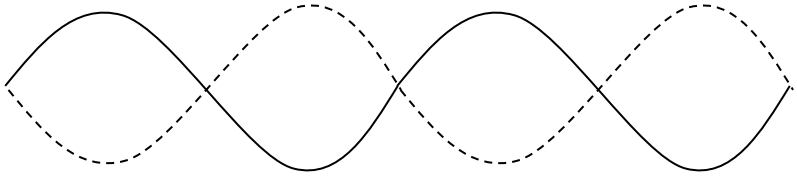
A *standing wave* is a wave pattern created by the interference of two continuous waves travelling in opposite directions in the same medium. It is called a standing wave because there are locations in the medium where the waves always interfere destructively and the particles do not move (or hardly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



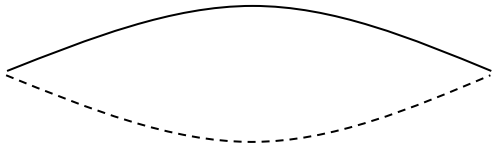
C: Standing Wave Patterns

You need a coiled spring, long measuring tape and a stopwatch. Two people will generate a standing wave in the spring – one will drive it and the other holds their end fixed to the ground. A third person will measure the lengths and time the motion. Stretch the spring so there is a fair bit of tension.

1. **Observe.** The **d**river will start with a very low frequency and gradually increase the driving frequency until it is as high as possible. Do standing waves occur with every possible frequency? What do you notice?

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 the length of the spring all the way up to the elbow of the person driving it. (That person's arm is like the last bit of the spring). Measure the period of the standing wave. Complete the first row in the chart below.

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

Mode	# of Anti-Nodes	# of Nodes	Length (λ)	λ (m)	T (s)	f(Hz)	Diagram
1	1	2	½				
2							• •
3							• •

4. **Reason.** Describe the patterns you see in each column when the oscillation mode increases.

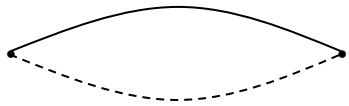
5. **Predict.** What is the standing wave pattern and all its characteristics for the 5th mode. Sketch it below.

SPH3U: Standing Wave Homework Name:

A: Thinking About Standing Wave Patterns

1. **Explain.** Why is there a node at each end of the stranding wave diagrams we drew for our spring in class?

2. **Explain.** We decided that the first mode or standing wave pattern had a length of just half a wavelength. Explain how we can tell. Sketch the complete wave.



Another label used to describe which mode (standing wave pattern) a medium is vibrating in is the *harmonic*. We say that a spring vibrating in its *first harmonic* when it is vibrating in the simplest possible standing wave pattern (the least number of nodes)..

B: 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?

C: The Wave Machine

A wave machine behaves differently than a spring does. We can create a standing wave by driving the rod at the end of the machine up and down with the right frequency. The rod at the other end is free to move up and down.

1. **Reason.** Is a node or an antinode located at the end of the machine where we are driving a rod up and down? Explain.

2. **Represent.** At the other end of the machine, the last rod moves up and down a great distance. The standing wave diagram for this situation will look quite different from the ones we drew for the spring. Draw the standing wave diagram for the first and second harmonics of the wave machine. (Hint: the first harmonic has only one node.) Label the nodes and antinodes.

3. **Calculate**. The wave machine has a length of 84 cm and a wave speed of 0.93 m/s. What are the wavelengths and frequencies of the first and second harmonic?

SPH3U: Resonance Homework Name:

1. **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.

2. **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.

3. **Reason.** You want to have resonance occur in a spring stretched out along the ground. You try it out and notice that it is not resonating. What are two different changes you could make about the situation which will ensure resonance occurs? (Hint: What is the condition for resonance to occur?)

4. **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.

It is possible for an object to resonate at many different frequencies. This set of frequencies or harmonics is called the *harmonic series*.

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: _____
0 1 2 3 4 5

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 object will *resonate* when the *driving frequency* matches the 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 is much 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. **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.

4. **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

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

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

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

C: Wine Glass Resonance

1. **Observe.** You will use a wine glass at the front of the classroom. Gently tap the side of the glass. You hear a sound which corresponds to the glass vibrating at its natural frequency.

2. **Observe.** Wet the tip of your finger. Slowly and gently rub it around the rim of the glass until you hear a sound. How does the frequency of the sound (the pitch) compare with the ding you heard when tapping it?

This is an example of resonance. Your wet finger skips across the edge of the glass providing the driving force and causing the wine glass to vibrate at its natural frequency.

3. **Predict.** What could you do to change the natural frequency of the glass? (Hint: think of water!) Make a prediction: How would the change you describe affect the natural frequency?

4. **Test.** Test this out. Describe your results.

SPH3U: Sound Waves

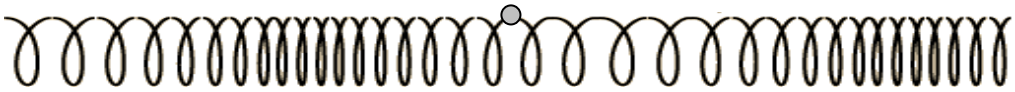
Recorder: _____
Manager: _____
Speaker: _____
0 1 2 3 4 5

A: Longitudinal Waves

1. **Explain.** All of the waves we have studied so far have been transverse waves. Remind yourself: What is a transverse wave?

2. **Observe.** You need a slinky segment for the next part of this investigation. Stretch it out across your desk. Attach a small piece of tape to a coil near the middle of the slinky. Stretch out the slinky with a fair amount of tension. **Don't over-stretch the slinky and damage it!** Have someone pull the coils towards the hand of the person holding down an end. Release the coils and describe what you observe.

3. **Represent.** Illustrate with arrows how the piece of tape moves. Label its equilibrium position.



The particles in a *longitudinal* wave move parallel to the direction of the wave pulse. A longitudinal wave will cause some regions of the medium to become compressed, producing a *compression* where the density of the medium has increased. It will also cause some regions to become stretched out, producing a *rarefaction* where the density of the medium has decreased.

4. **Represent.** Label the regions of compression or rarefaction in the diagram above.

5. **Observe and Represent.** Use your slinky to create a longitudinal wave with a larger amplitude. Illustrate the motion of the particle on the diagram above and label is "large amplitude".

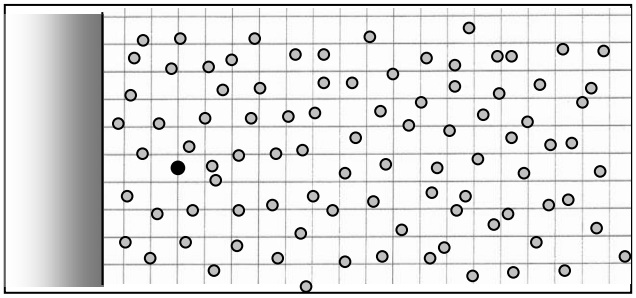
6. **Explain.** What does amplitude mean for particles in a longitudinal wave?

B: 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.

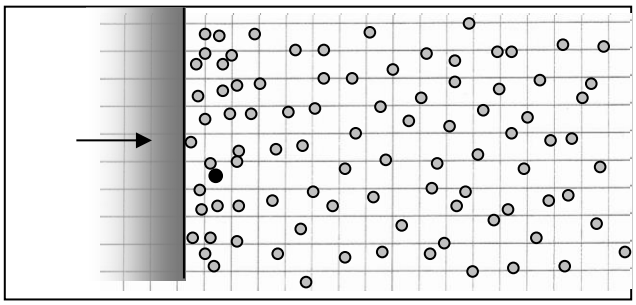
When you put on your ear phones and crank up your mp3 player, a tiny membrane in the earphone vibrates back and forth creating a sound wave in the air near your ears. The diagram below shows the membrane and the air particles, both initially at rest.

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

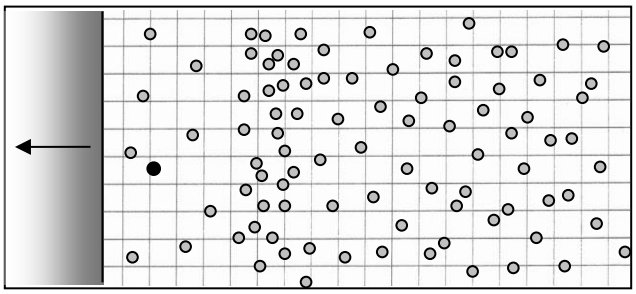


If we could watch a video of these particles, they would be travelling in random directions, bouncing off one another. This is the equilibrium state of the medium of air. When we study longitudinal waves, we will ignore the random vibrations of the air molecules.

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 above.

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?

The regions of high and low pressure travel outwards from the vibrating object. If we could see this, it would look like a spherical shell expanding outwards from the source. The individual air particles **do not** travel any great distance – typically around a billionth of a metre (nm). They simply oscillate back and forth, more or less in place (ignoring the random motions). It is the regions of high and low pressure that move outwards.

6. **Predict.** Isaac holds a tissue near the front of a speaker creating a loud sound. He claims that if he releases the tissue, it will "blow away" due to the sound waves travelling outwards like a wind. You are not sure, but propose an experiment: Put a speaker in a sealed plastic bag. What prediction would Isaac make for what happens to the sound? According to our model of a sound wave above, what do you predict will happen? We will test this as a class.

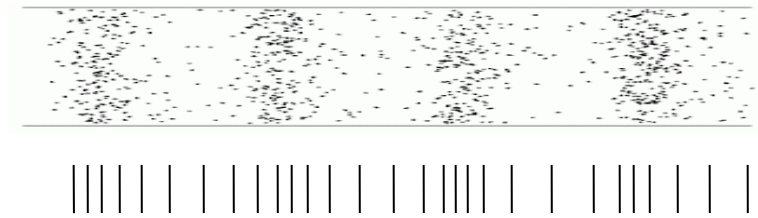
   Isaac:

   You:

C: Representing Sound Waves

Drawing realistic sound waves or any type of longitudinal wave is very challenging, but luckily it can be simplified using a nice trick.

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 below a data point for each high and low pressure region on the diagrams above.

4. **Predict.** The pressure will change smoothly from high to low. What will the complete the graph look like? Sketch this on the graph.

A sound wave can be represented on the computer using a microphone. When the high and low pressure regions reach the microphone, they push against the microphone surface. The electronics convert the changing pressure into a changing voltage which the computer can read and display in a graph. We will call this the *pressure graph* of a sound wave. A pressure graph may have either time or position along the horizontal axis, like the earlier graphs we studied.

5. **Test.(together)** Use the microphone attached to the computer to verify your predicted pressure graph for the sound wave created by a vibrating tuning fork. Be sure to strike the fork with a proper mallet or on something soft. Sketch what you observe and label the axes of the graph.

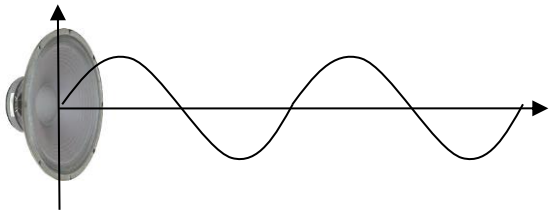
6. **Reason.** In the pressure graph, is the interval between two adjacent crests the period or wavelength of the sound wave? Explain how you can tell. Label these intervals with arrows.

SPH3U: Sound Waves Homework Name:

1. A speaker creates a steady sound wave, represented by a pressure-position graph.
   (a) **Represent.** Complete an illustration of the air particles and "slinky-coils" according to this graph.

   (b) **Interpret.** For each diagram, decide whether it illustrates the wave's period or wavelength. Label this on each.

   (c) **Reason.** We increase the frequency of the sound the speaker makes. Explain how the three diagrams will change.

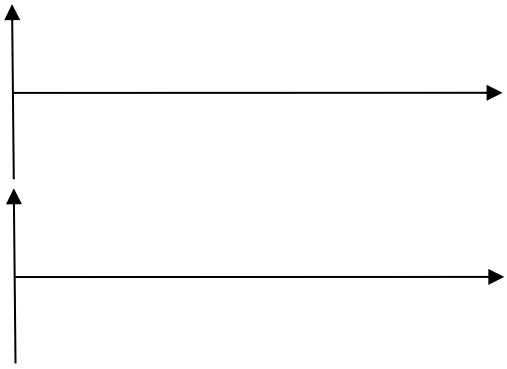


2. A dust particle floats in the air in front of a speaker. The speaker is turned on and produces a sound with a constant frequency and amplitude.
   (a) **Represent.** Describe the motion (including direction!) of the dust particle. Illustrate this on the diagram.

• dust particle

   (b) **Reason.** The frequency and amplitude of the sound are both doubled. What will happen to the motion of the dust particle?

   (c) **Represent.** Sketch a displacement-time graph for the dust particle in each situation above. Label the differences seen in the two graphs.



We can use a *displacement-time* graph to represent the displacement of a particle from its equilibrium position at each moment in time. This type of graph is different from the *pressure* graphs we studied in class. A pressure graph does not show how far a particle has been displaced from equilibrium.

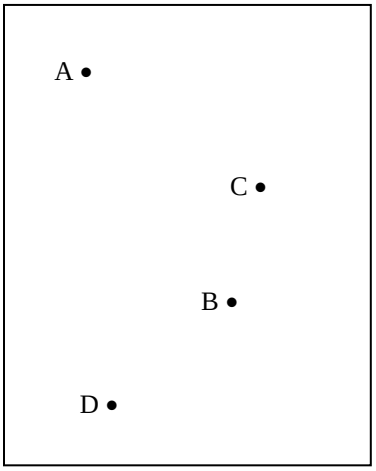
3. **Calculate and Explain.** A dust particle floats in the air in front of a speaker. Initially the speaker produces a sound that causes the dust particle to move with an amplitude of 2 nm (1 nm = 10^{-9} m) and a frequency of 256 Hz. Later the speaker produces a sound that causes the dust particle to move with an amplitude of 4 nm and a frequency of 180 Hz. In which situation will the dust particle move the greatest distance in 10 seconds? Explain your reasoning.

SPH3U: The Propagation of Sound

Recorder: _____
Manager: _____
Speaker: _____
0 1 2 3 4 5

A: Two Dimensional Sound Waves

A student is sitting in a classroom and her cell phone rings! During class! This scandalous event is shown in the diagram to the right. Four students are also shown in the diagram and they are labelled A, B, C, and D. Student B has the ringing phone.



1. Which students can hear the sound from the cell phone? Explain. (There are no obstructions in the room.)

2. Technically speaking, do all the students hear the ring at the same time, or different times? Explain.

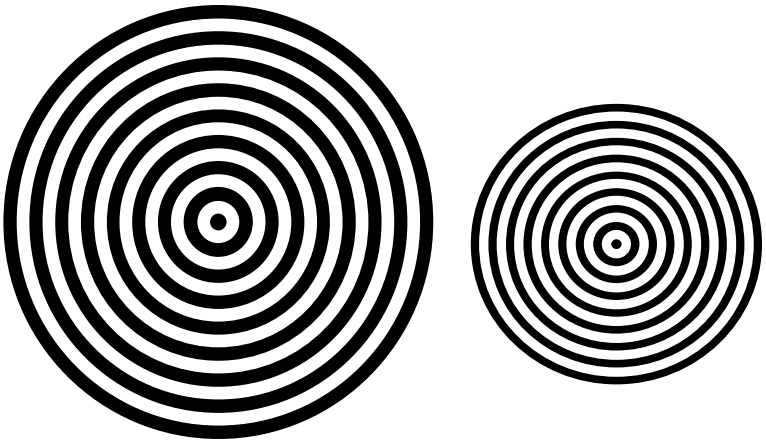
If we could picture a sound wave, we would see a circular wave (well, actually a spherical wave) of compressions and rarefactions travelling outwards from the source. We can represent these regions of compression and rarefaction as circles. For convenience, we will choose to have the dark line represent the crest of the wave (compression).

3. A pure sound tone which has only one frequency will produce a regular, steady series of circles. Two examples are illustrated to the right.
   (a) Use arrows to label the crests (compressions) and troughs (rarefactions).

   (b) What does the distance from one dark band to the next represent?

   (c) Which wave has the higher frequency? Explain how you can tell.

   (d) Which wave has been traveling for the most time? Explain how you can tell.



4. Draw a circle showing a sound wave that has just reached student D. Who has already heard this sound? Who has not heard it yet?

5. Normally we don't notice the difference in times when each student hears the sound. Why?

6. Can you think of any situation where you have noticed a delay in the sound that you hear? Describe what is happening during one such experience.

B: The Speed of Sound

The speed of sound in air is given by the equation: $v = 331 \text{ m/s} + \left(0.59 \ \frac{m/s}{^oC}\right)T$, 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. What is the speed of sound in this room right now? You may need to make a simple measurement.

2. Describe a situation in which you have heard sounds waves travelling through
   (a) a liquid:

   (b) a solid:

3. What would happen in space? Imagine a foolish astronaut takes off his/her helmet and shouts!

SPH3U: The Propagation of Sound Homework

1. **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°C.
   (a)What is the speed of the wave in the violin string? What is the speed of the wave in the air?

   (b) Explain how you chose which information to use in the two calculations above.

2. **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?

3. **Calculate.** You are at a large outdoor concert, seated 300 m from the speaker system. It is a cool summer evening with a temperature of 18°C. The concert is broadcast live via satellite (at the speed of light, 3.0×10^8 m/s). Consider a listener 5000 km away from the broadcast. Who hears the music first, you or the listener and by what time difference?

SPH3U: The Interference of Sound

Recorder: _____
Manager: _____
Speaker: _____
0 1 2 3 4 5

A: Fiddly Dee, 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.

B: 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. **Reason.** The tuning fork with a resonance box attached it an example of, surprisingly enough, resonance. Explain how the resonance is working in this situation.

3. **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.

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

Small differences in a wave are often very hard to notice until that wave interferes with another wave. This is the principle behind the technique of *interferometry* which is used in many fields of science. (Check out the Wikipedia entry!)

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

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

7. **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?

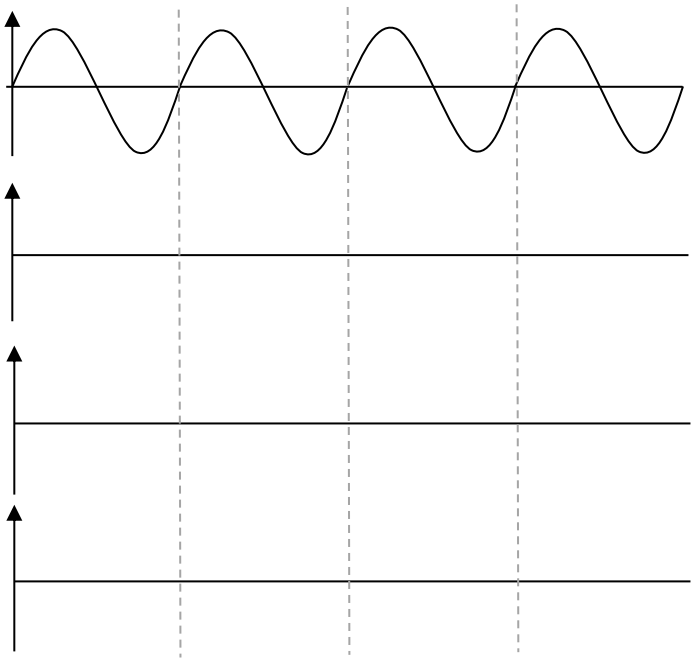
8. **Observe.** Measure the frequency of the pulsing pattern.

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.

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

C: 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*. What characteristic of the wave do you think would change? This is a hard one – just make a guess!

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

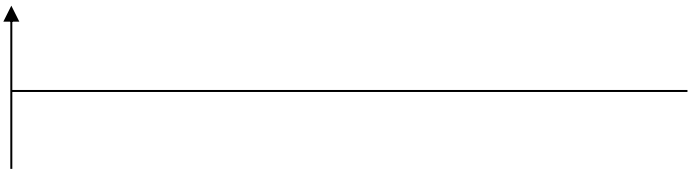
   (a) loudness:

   (b) pitch:

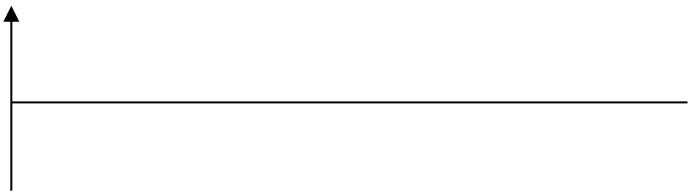
   (c) timbre:

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.

5. Next, we will blow on the microphone which will create *white noise*. Describe (don't draw yet) what you think the graph for white noise might look like.



6. In a previous investigation, we explored the phenomena of beats. Describe (don't draw yet) what you think the graph might look like.



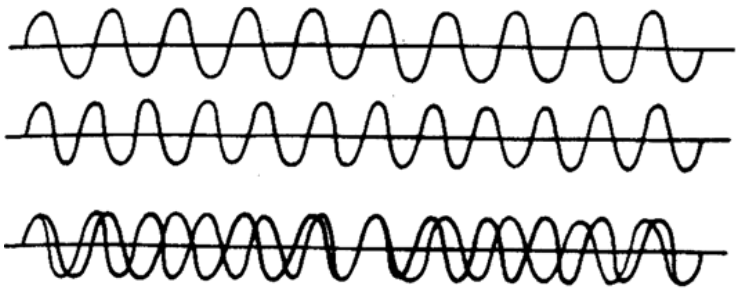
SPH3U: Interference of Sound Homework Name:

Musicians know all about beats. It is very hard to tune an instrument simply by playing the note and deciding if it sounds right. It is much easier to play the note at the same time as the in-tune note, have the two notes interfere and listen for the beats that result.

1. **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.

2. **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.

3. The top two graphs to the right show two sound waves with slightly different frequencies. The air temperature is 21°C. The bottom graph shows the two waves overlapping but without interfering.
   (a) **Calculate.** Measure the wavelength directly off the page. What is the wavelength and frequency of each of the two waves?

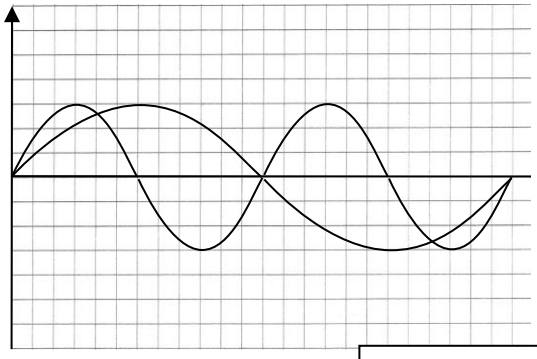


   (b) **Calculate.** What is the beat frequency?

   (c) **Represent.** On the bottom graph label where constructive and destructive interference will occur. Label where the sound will be loud and soft.

4. **Calculate.** A tuning fork of unknown frequency makes three beats per second with a standard fork of frequency 384 Hz. The beat frequency decreases when a small piece of wax is put on a prong of the unknown fork. What is the frequency of this fork?

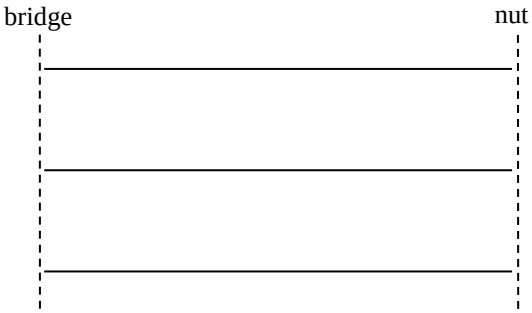
5. **Calculate.** Here is an example of two harmonics sounding at the same time and interfering, creating a new timbre. Use the superposition principle to find the shape of the graph when they interfere!



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 violin string when we play the low A, the E and the high A. Note that the original, 32.5 cm portion of the string is shown in the diagram. 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.** When a violin string produces the note A-440, a particle of the string at the antinode moves 2 mm from its equilibrium position. What distance will this particle have moved after 2 seconds?

4. **Calculate.** You are practicing your violin and play an A-440. 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?

5. **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?

6. **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?

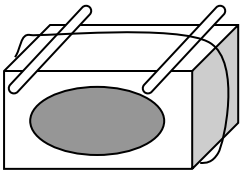
SPH3U: The Vibrating String

Recorder: _____
Manager: _____
Speaker: _____
0 1 2 3 4 5

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*.

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.

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.

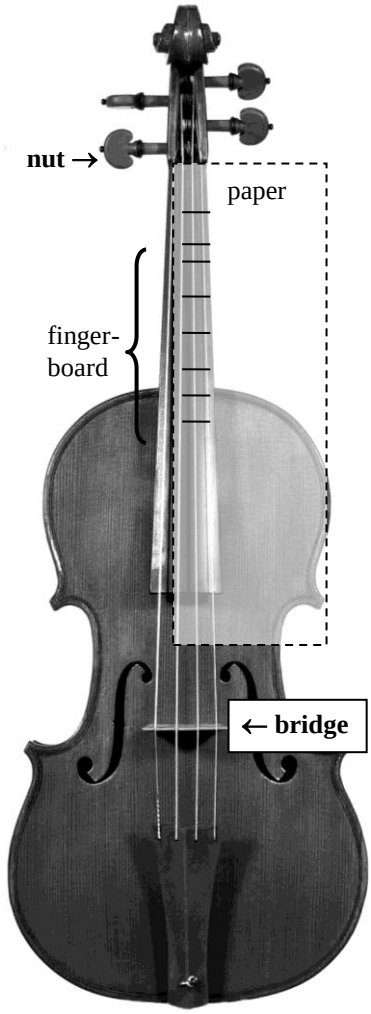
6. Put both on to the box side by side. Do the sounds agree with your prediction? Offer a reason why or why not.

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

B: Frequency and Length – A Violin 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 violin has its "A" string tuned to the pitch known as A-440, meaning a frequency of 440 Hz. Its four strings vibrate between the nut and the bridge – a distance of 32.5 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-440 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′		

Note: **you do not** need to memorize any intervals for a test or exam!

Sample calculation:

SPH3U: Resonance in Air Columns

Recorder: _____
Manager: _____
Speaker: _____
0 1 2 3 4 5

You may, or may not, be an accomplished bathroom shower singer. If you are, you are likely well acquainted with resonance in the shower. You might have noticed that while singing, if you find the right pitch, the loudness of your voice increases significantly and surprisingly. Something about the sound wave you created matched the volume of air you are in and resonance was the result!

A: Searching for Resonance in Air

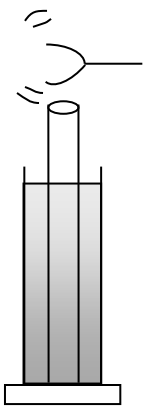
1. **Reminder.** What was the condition for resonance to occur?

2. **Speculate.** What characteristics determine the natural frequencies for a fixed volume of air like your shower?

3. **Reason.** You have a hollow tube with an adjustable length and a variety of tuning forks. You hold the vibrating fork near the opening of the tube, but hear nothing special (no resonance). Explain what characteristics of this situation you might change in order to produce resonance.

B: 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:

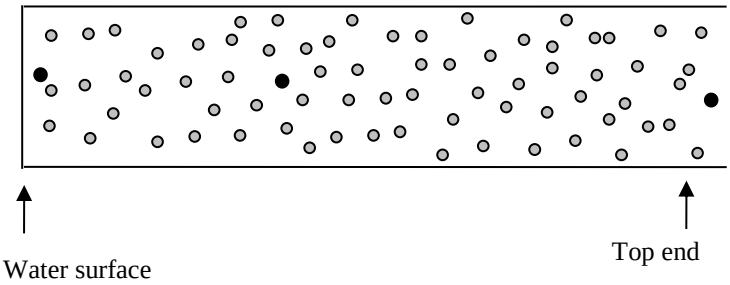
   Marie:

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

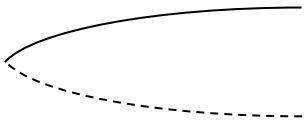
A standing wave forms when waves travel through a medium, reflect off the ends and interfere with waves travelling in the opposite direction (just like we studied with the springs). Sounds waves travel up and down the air column and reflect off the bottom end (the water surface) and the top end (the 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.** The diagram to the right represents the air particles in your air column (tilted sideways). Use arrows to show the direction of the displacement of the highlighted air particles. Label the boundary conditions at each end. Describe what direction the air particles move in and what direction the sounds waves move in.



6. **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.



7. **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?

C: 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. **Reason.** As an example, think of a string fixed at both ends with a standing wave. The wavelength of the standing wave is not changing, but the length of the string is. Draw some sample standing wave diagrams to help illustrate how this is possible.

5. **Find a Pattern.** As the length of the medium gradually increases, what happens to the number of nodes and anti-nodes?

6. **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 only row 1 of the chart.

Resonant Length	Length of column (cm)	# of λ	Standing Wave Diagram
1			
2			

7. **Explain.** Based on your measurement and the diagram, explain how you can determine the wavelength of the sound wave.

8. **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.

9. **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 (together)

For this investigation you will use a large cardboard tube and a signal generator with a speaker set up at the front of the class. The cardboard 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. **Observe.** Time to use the equipment! Adjust the frequency of the signal generator and listen for the resonance. How can you tell when you have reached a resonance frequency?

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 14°C. 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 (26°C) 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: 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, which describes the different standing wave patterns for string fixed at both ends.

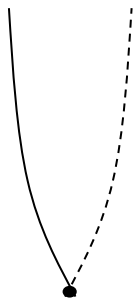
Mode	Sketch	# of Anti-nodes	# of Nodes	# of λ	Frequency Compared to f_o	Harmonic
1		1	2	½	$1f_o$	1st
2						
3						
7						

2. How are the following quantities related to the harmonic?
   a) The number of antinodes b) The number of nodes c) The number of wavelengths

3. In columns of air, the pattern of harmonics is slightly different and this depends on the type of air column. Complete the chart below.

Open-Closed Columns

Mode 1	**Mode 2**	**Mode 3**
# of nodes = **1** # of anti-nodes = **1** # of λ = **¼** f = **1 f_o**	# of nodes = # of anti-nodes = # of λ = f =	# of nodes = # of anti-nodes = # of λ = f =



Open-open Columns

Mode 1	**Mode 2**	**Mode 3**
# of nodes = 1 # of anti-nodes = 2 # of λ = ½ f = 1 f_o	# of nodes = # of anti-nodes = # of λ = f =	# of nodes = # of anti-nodes = # of λ = f =

SPH3U: Build a Musical Instrument!

Hand in this sheet with your instrument and poster

Group Members: _____

Instrument Name: _____

Proposal due date: _____ Instrument and poster due date: _____

Your task is to design and build a musical instrument, and then present it to the class.

Instrument Specifications:

- The instrument must be capable of playing a one octave (8 note) major scale.
- You may not use parts for actual instruments except for strings
- It cannot be a rubber band tissue box or set of glasses (glass harmonica)!
- **You may not use the school shop for this project**! Please speak to your teacher if you need help with any materials.

Presentation:

- Give a two-minute maximum description of the instrument – how it works, how you built it
- Perform a major scale and simple song
- Each group member must participate in the presentation

Poster:

- Use diagrams or photos of your actual instrument to explain how it works and how it creates the different notes. Any images you use must be your own.
- Include standing wave diagrams and sample calculations to assist your explanations.
- Physics terminology is important!
- Size = 8½ x 11 page

Proposal (5 marks)

Handed-in on time, diagram of instrument design, time-line for group work, list of who does what, reflects final instrument	

Poster (10 marks)

Explanation (5 marks): physics concepts used and well explained, clear organization, application to instrument clearly explained, calculations correct, diagrams correct	
Grammar, Spelling (2 marks): correct English usage	
Appearance (3 marks): visually pleasing, clear layout and organization, use of headings, diagrams	

Instrument (25 marks)

Design and Construction (10 marks): construction neatly done, sturdy workmanship, good use of materials, interesting or creative ideas, challenging design	
Musical Capabilities (10 marks): has 8 note major scale, in tune, easy to play, good sound	
Visual Appearance (5 marks): attractively made or decorated	

Total Mark: /40