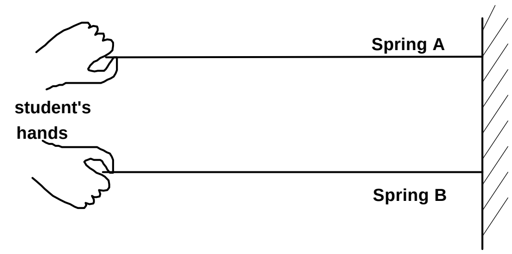
Appendix A: Propagation and Superposition of Wavepulses Tutorial

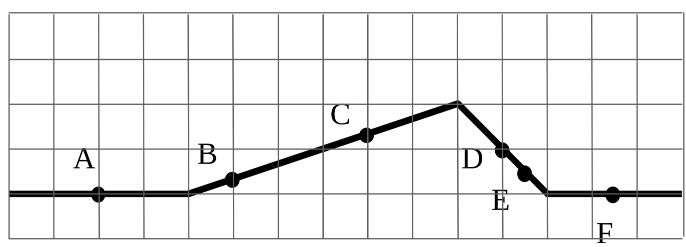
Name ____________________

Pretest

1. A demonstrator holds two long, taut springs attached to a distant wall (see figure). The demonstrator starts to move both hands at the same time and in the same direction. The wavepulses created by the demonstrator both move toward the wall, but one reaches the wall sooner than the other. How can you account for the difference in speed of the two pulses? List all possible ways.

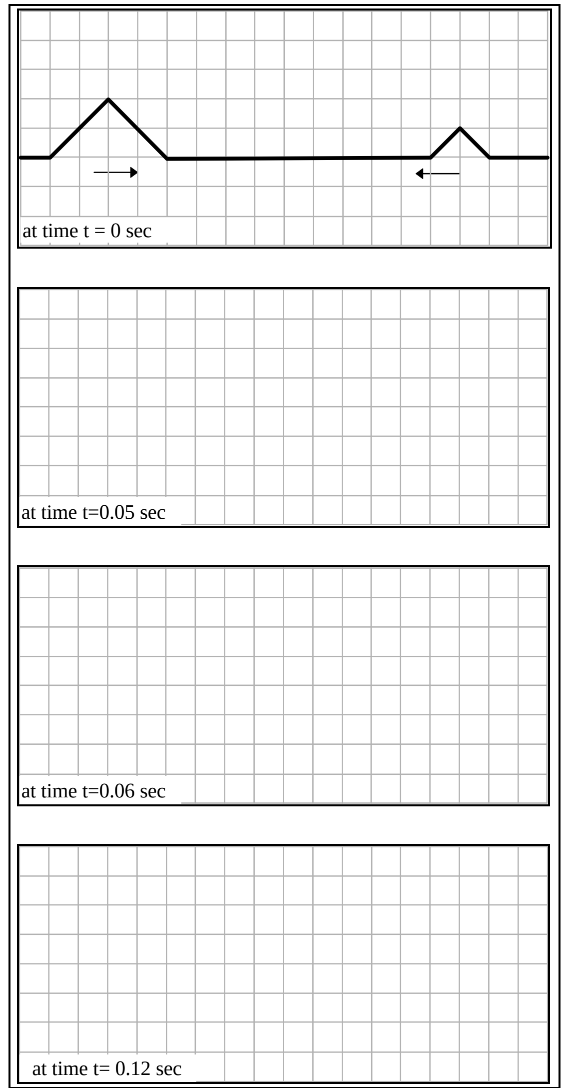


2. The solid line shown at right indicates the position of a wavepulse traveling to the right on a spring. Each dot on the line indicates the location of a piece of tape on the spring. Rank the speed of each piece of tape from highest to lowest. Explain how you arrived at your answer.



(over)

3. Consider the following situation. Two wavepulses are moving toward each other on a spring (see figure at right). The wavepulses are shown at time t = 0 sec. Each wavepulse moves at a speed of 1 m/sec (=100 cm/sec). Each block represents 1 cm (=0.01 m).



A. Sketch the shape of the string at time t = 0.05 sec in the space at the right. Explain how you arrived at your answer.

B. Sketch the shape of the string at time t = 0.06 sec in the space at the right. Explain how you arrived at your answer.

C. Sketch the shape of the string at time t = 0.12 sec in the space at the right. Explain how you arrived at your answer.

Propagation and Superposition of Wavepulses

I. Demonstrations and Videos of Wavepulses on a Spring

A. A facilitator will create wavepulses on a stretched spring by quickly moving his or her hand back and forth exactly once. The facilitator will use different hand motions to create wavepulses with different amplitudes and shapes. Observe the motion of the wavepulse and of the spring in each case. A piece of tape has been attached to the spring near its middle.

How did the motion of the tape compare to the motion of the wavepulse for each type of wavepulse that you observed?

Did the speed of the hand motion affect the speed of the wave? Explain.

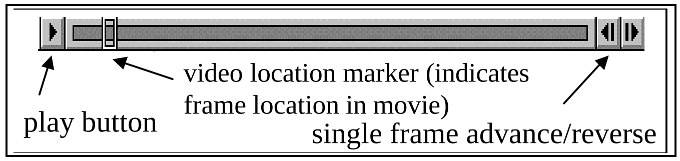
Did the amplitude of the wave affect the speed of the wave? Explain.

Did the tension in the spring affect the speed of the wave? Explain.

The demonstrator will create a pulse by pulling a piece of the stretched spring toward him or herself and releasing it. Compare the motion of the tape in this situation to the previous motion of the tape.

You have described the difference between transverse and longitudinal waves. In this tutorial, we focus only on transverse waves.

B. We have made videos of wavepulses traveling on identical springs. On your computer, open ***Shapes.mov***. Use the controls shown below to play the video on your computer. If the video plays too quickly, use the single advance buttons to go frame-by-frame. To return to the beginning of a movie, drag the "video location marker" to the left on its slider or click on the left edge of the play strip.



Imagine you are holding each of the springs in the video.

1. Describe what you see in the video. What hand motion could you use to create wavepulses having these shapes?

Open and play the movie ***Amplitud.mov***.

2. Describe what you see in the video. What hand motion could you use to create wavepulses having these shapes?

Consider that one of the springs used in questions 1 and 2 is stretched out to a greater length.

3. What physical properties of the spring have been changed by doing this? Explain.

Open and play the movie ***Stretched.mov***. In this video, one of the springs has been changed as described in question 3, the other is unchanged.

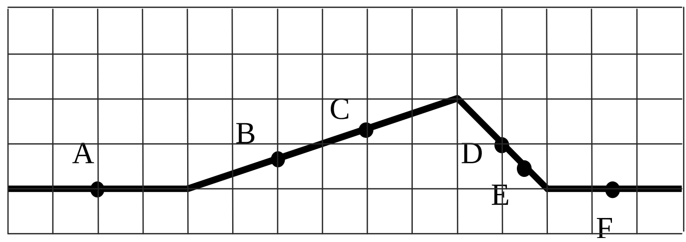
4. Describe what you see in the video.

5. Based on your observations, how can you affect the speed of a wave traveling along a spring? What changes can you make that *do not* affect the speed of the wave? Explain.

6. Are your observations consistent with the equation that describes the speed of a wave on a string, which you learned in class? Resolve any discrepancies.

II. Analysis of a single wavepulse

The solid line shown at right indicates the position of a wavepulse traveling along a spring at a time t_0. Each block represents 1 cm. The wavepulse is moving to the right with a speed of 100 cm/s.



1. In the graph located above, sketch the position of the wavepulse after 0.01 sec has elapsed.
2. How can you use your diagram to find the velocity of a piece of the spring at time t_0 (e.g., the part of the spring labeled D)?

   Determine the velocity of the piece of spring located at position D at time t_0. Explain.

   Determine the velocity of the piece of spring located at position C at time t_0. Explain.

   Draw vectors on the diagram to represent the instantaneous velocity of the pieces of spring labeled A – F at time t_0. Draw your vectors to scale.
3. Compare the direction of motion of the wavepulse and of the spring.

III. Superposition of Wavepulses:

A. Open the movie ***SameSide.mov*** on your computer. Play the video.

1. Describe what happens as the two wavepulses meet. Discuss each pulse and the spring.

Use the single advance buttons to find the frame showing the moment when the two wavepulses overlap as completely as possible.

2. How could you determine the maximum displacement of the spring at the instant of perfect overlap? Explain.

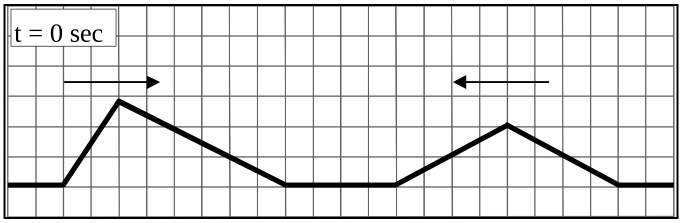
   Explain how you can determine the displacement of the spring at locations *other than* the point of maximum displacement at this instant.

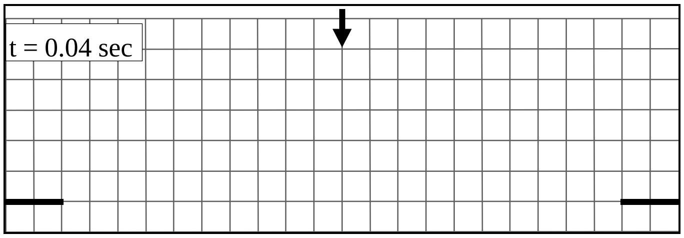
Find the frame *just before* the moment analyzed above.

3. Describe and sketch the shape of the spring.

   Account for the shape of the spring between the two peaks. Is your explanation consistent with the explanation you gave in question 2? Resolve any discrepancies.

B. Consider the following situation. Two wavepulses are moving toward each other on a spring (see upper figure at right). The wavepulses are shown at t = 0 sec. The left pulse moves at a speed of 1 m/sec (=100 cm/sec). Each block represents 1 cm (= 0.01 m).



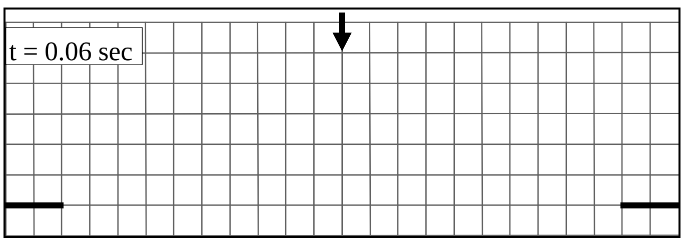


1. What is the speed of the *right* wavepulse? Explain.

2. Sketch the shape of the spring at time t = 0.04 sec in the figure above. Explain how you arrived at your answer.

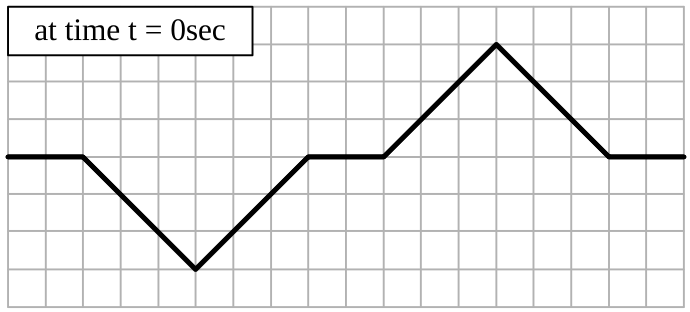
   How did you determine the displacement of the spring at the location of the gridline indicated by the arrow? Explain.

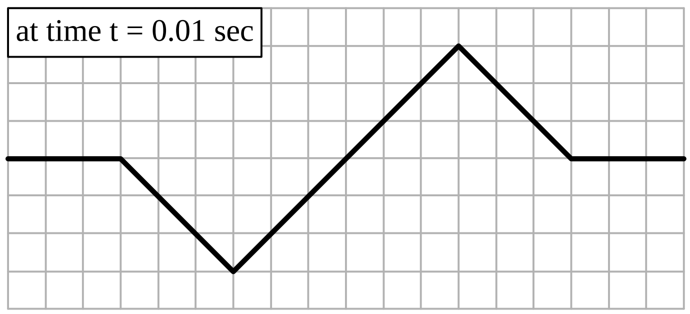
3. Sketch the shape of the spring at time t = 0.06 sec in the space at right. Draw your sketch to the same scale as above. Explain how you arrived at your answer.

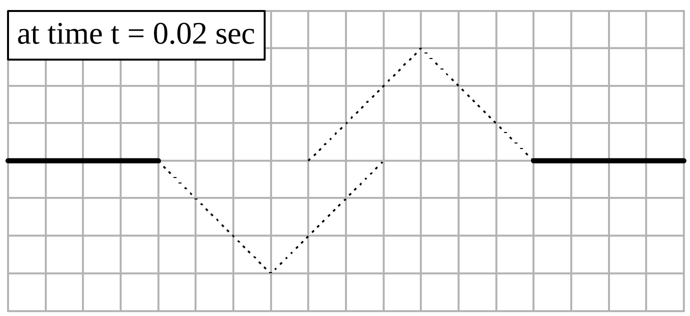


   How can you determine the displacement of the spring at *any location* and *any time* when two wavepulses overlap. Explain you reasoning.

C. Two wavepulses on opposite sides of a spring move toward each other at 100 cm/s. The diagrams below show the wavepulse locations at three successive instants, 0.01 s apart. (In the last diagram, the individual wavepulses are shown dashed.) Each square represents 1 cm.







1. Use the principle of superposition to find the shape of the spring at t = 0.02 sec. Draw it in the graph above. Make sure all of your group agrees on how you arrived at your answer before continuing.

The diagrams above and blanks for three further time steps are reproduced on the last two pages of this tutorial. Each person in your group should draw what the spring will look like for ONE of the times shown from 0.03 sec to 0.05 sec. Draw the shape of the **spring** for each of the instants shown. After constructing your diagram, discuss your results with the rest of your group until you all agree what the spring should look like at each instant.

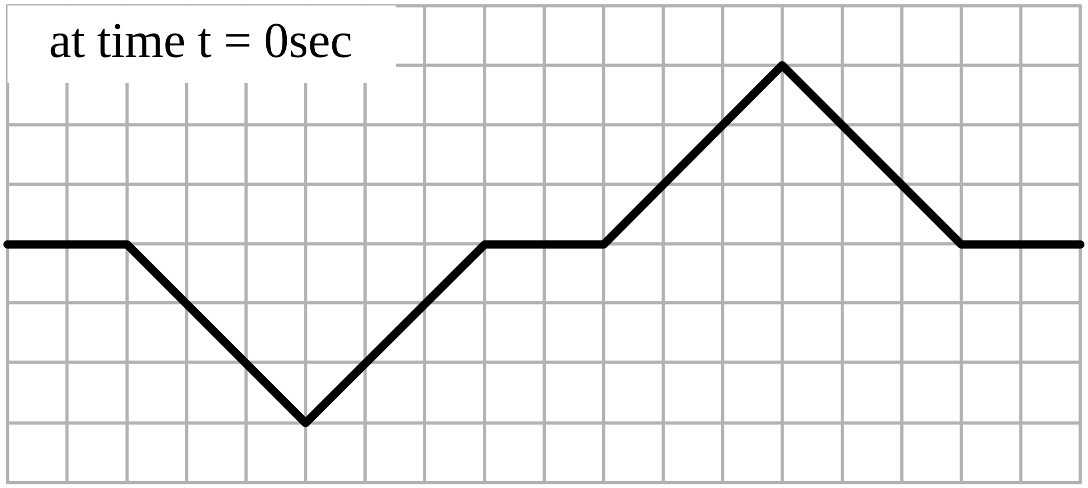
2. Are your graphs consistent with your explanation on the bottom of page 4? Resolve any discrepancies.

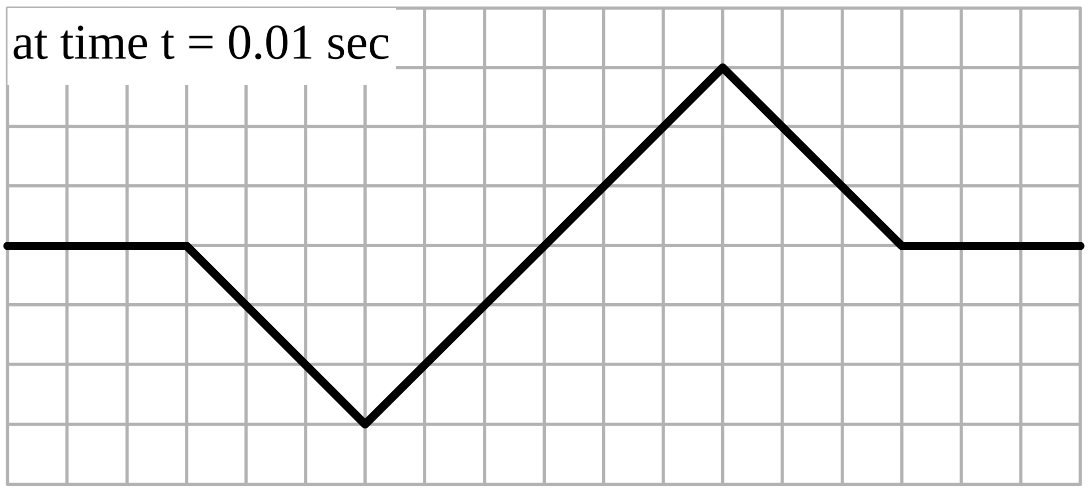
3. How can you account for the continued propagation of the wavepulses after the time
   t = 0.4 sec?

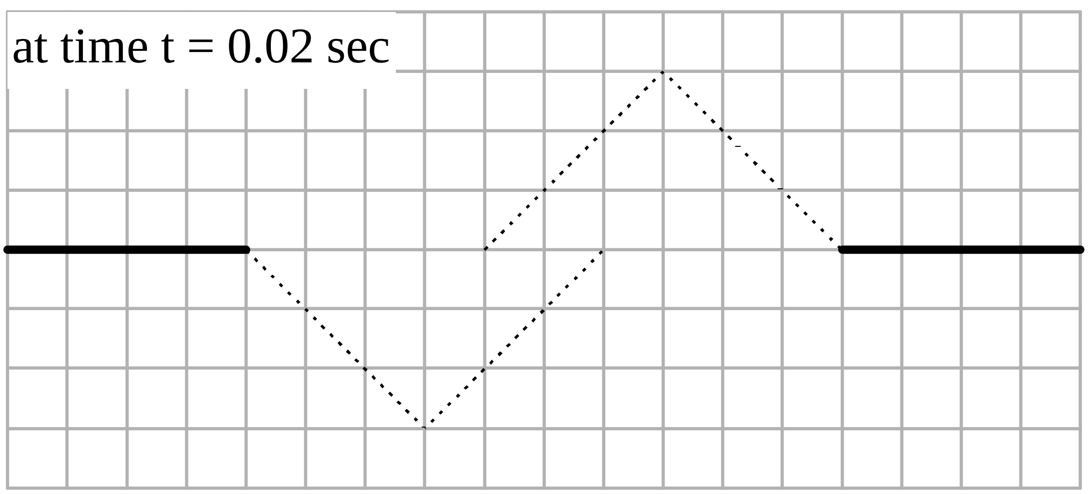
4. Sketch a graph of the velocity as a function of position for the spring at time t = 0.4 sec in the space below. Explain how you arrived at your answer.

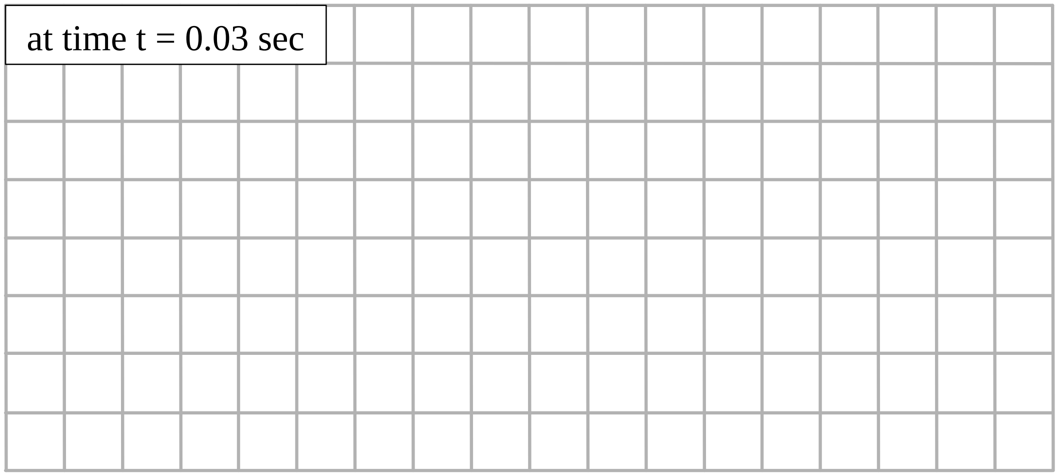
On your computer, open and play the movie ***Opposite.mov***.

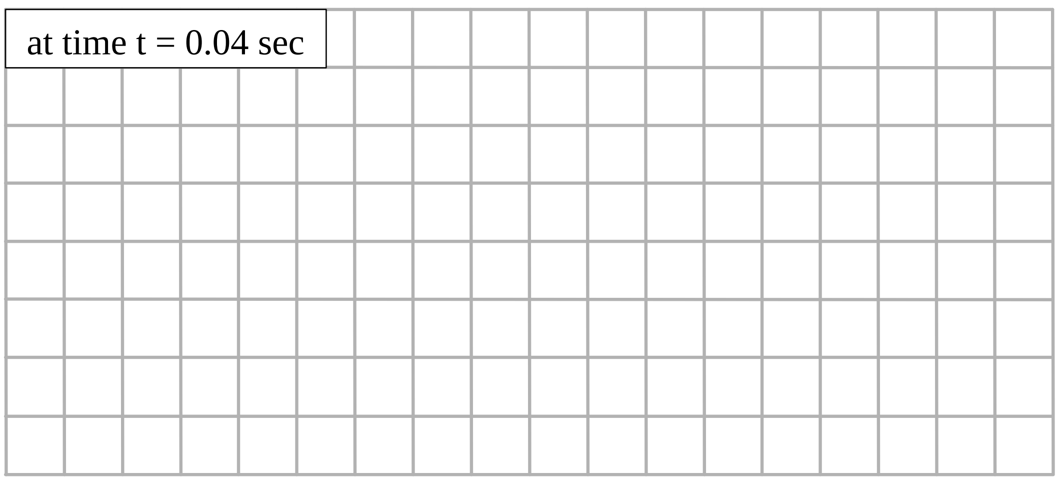
5. Is the movie consistent with the sketches you made on the large diagrams? Resolve any discrepancies.

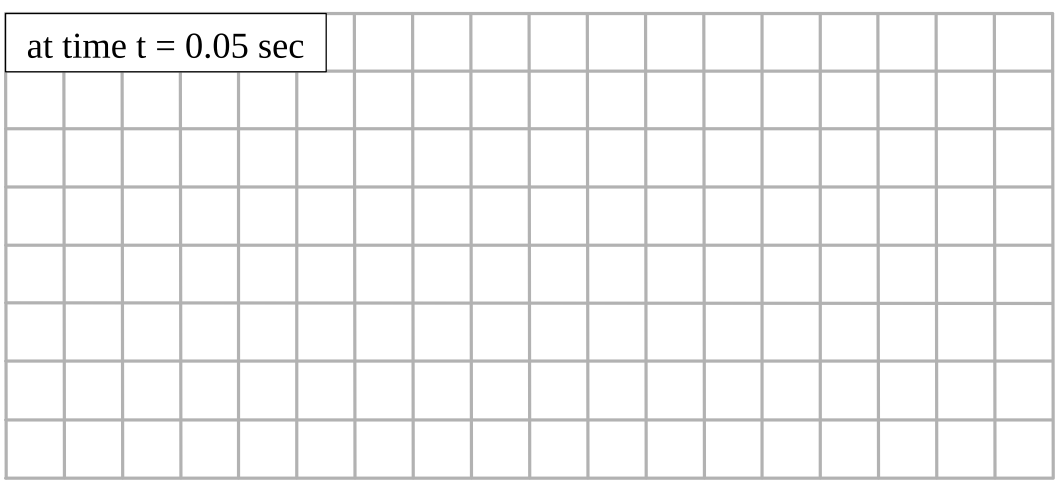

at time t = 0sec


at time t = 0.01 sec

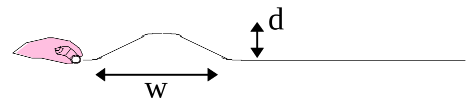

at time t = 0.02 sec


at time t = 0.03 sec


at time t = 0.04 sec


at time t = 0.05 sec

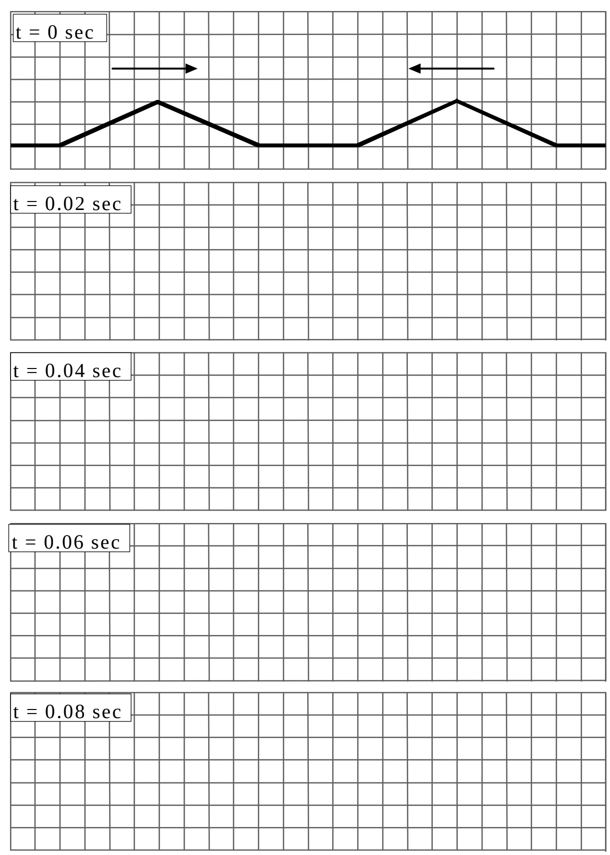
A. A method for generating a wavepulse is to move one end of a spring quickly up a distance *d* and then back down (see figure). The hand takes the same amount of time to move up as to move down. Consider a second wavepulse generated with the same amplitude, *d*, on a different spring (spring 2). It is observed that the wave speed on spring 2 is half that in the original spring (spring 1).



1. How can you account for the difference in speed of the wavepulse on the two springs? Explain.

2. What could you change about the creation of the second wavepulse or spring 2 so that the wavepulse on spring 2 traveled at the same speed as the wavepulse on spring 1? Explain.

B. The diagram at right shows two wavepulses at time t = 0 sec moving toward each other on the same side of a spring. Each pulse is moving at a speed 100 cm/sec. Each block represents 1 cm.



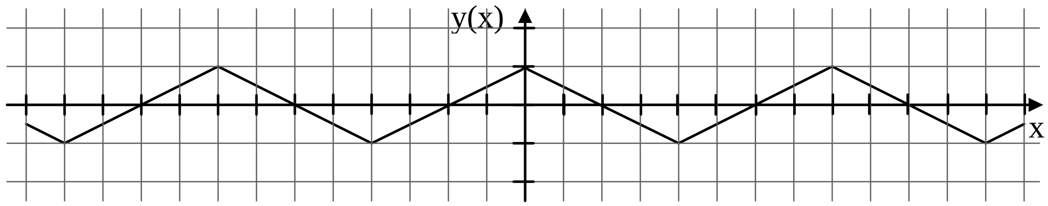
1. In the grids provided to the right, sketch a sequence of diagrams that show both the positions of the individual pulses (with dashed lines) and the shape of the spring (with a solid line) at 0.02 sec intervals.

2. Draw velocity vectors to indicate the *velocity* of the piece of spring located at the horizontal midpoint of each square at time t = 0.04 sec. Explain how you arrived at your answer.

Propagation and Superposition - Tutorial Homework

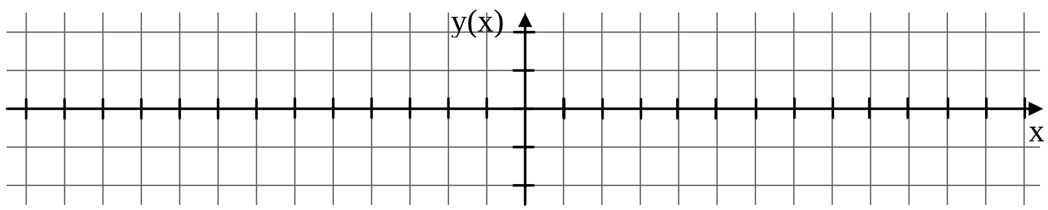
Bridging Problem

Two infinite (continuing in both directions) waves are traveling along a taut spring of uniform mass density. At time t = 0 seconds, the waves have the same shape and are in the same location. One is traveling to the *right*, the other is traveling to the *left*. *One* of the waves is shown in the space below. (At time t = 0 sec, the other wave's peaks perfectly overlap the first wave's peaks.) In the diagram, each block represents 10 cm. After t_0 seconds, the wave traveling to the *right* has traveled 20 cm.

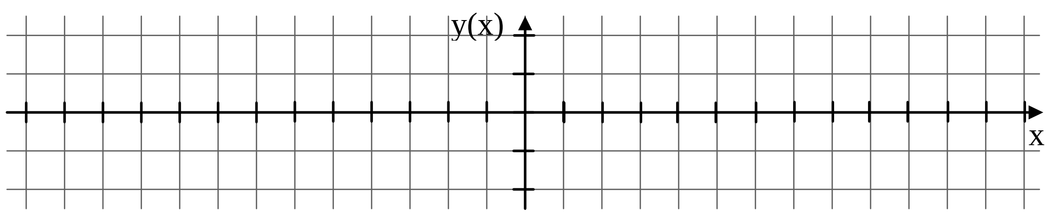


a) Compare the speed of the two waves. Explain how you arrived at your answer.

b) Using two different colors of pen or pencil, sketch each individual wave at time t_0 in the graph below. (Do not sketch the shape of the spring, just each wave.) Indicate the direction that each wave is traveling on your sketch.



c) In the graph below, sketch the shape of the spring (with both waves traveling on it) at time t_0. Explain how you arrived at your answer.



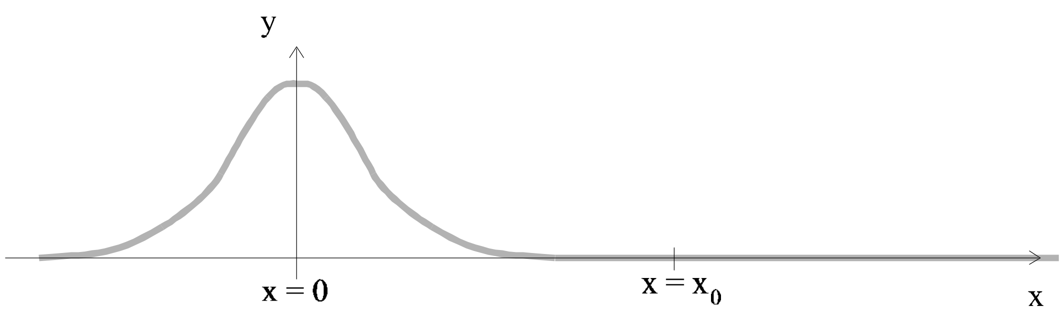
d) If t_0 = 0.2 sec, find the velocity of the piece of spring located at x = 0 at the instant you have drawn in part c. Explain how you arrived at your answer.

Appendix B: Mathematical Description of Wavepulses Tutorial

Name

Pretest

1. Consider a pulse propagating along a long, taut spring in the +x-direction. The diagram below shows the shape of the pulse at t = 0 sec. Suppose the displacement of the spring at this time at various values of x is given by $y(x) = Ae^{-\left(x/b\right)^2}$.



A. On the diagram above, sketch the shape of the spring after the pulse has traveled a distance x_0, where x_0 is shown in the figure. Explain why you sketched the shape as you did.

B. For the instant of time that you have sketched, find the displacement of the spring as a function of x. Explain how you determined your answer.

(over)

2. The experiment described in question 1 is repeated, except that at t = 0 sec, $y(x) = Ae^{-\left(x/c\right)^2}$, where c is twice as big as b (c = 2b).

   A. Compare the shape of the *pulse* in this experiment to the shape of the *pulse* in the previous experiment. Explain.

   B. Compare the motion of the *pulse* in this experiment with the motion of the *pulse* in question 1. Explain.

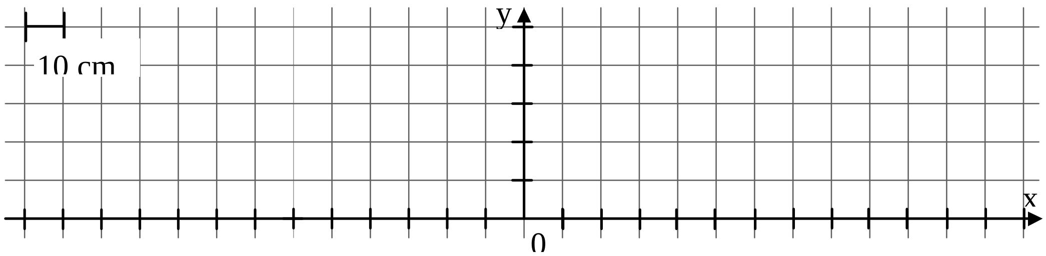
   C. Consider a small piece of tape attached to the spring at x_0. Compare the motion of the *piece of tape* in this experiment with the motion of the *tape* in question 1. Explain your reasoning.

Mathematical Description of Wavepulses

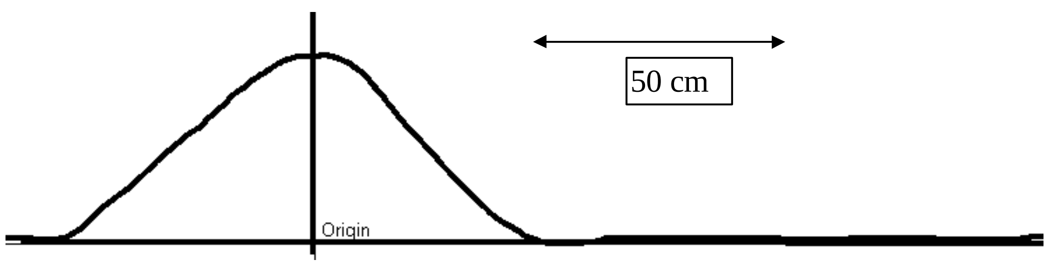
I. Describing the Movement of a Wavepulse

A. At t = 0 sec, the displacement of the spring from its equilibrium position can be written as a function of x, $y(x) = \frac{50cm}{(x/b)^2 + 1}$, where b = 20 cm.

1. Sketch the shape of the spring at t = 0 sec in the graph below. Use a scale where each block represents 10 cm on a side.



2. The digitized photograph below shows a wavepulse propagating to the right. The wavepulse can be roughly described by an equation of the form $y(x) = \frac{A}{(x/b)^2 + 1}$. Using the indicated scale, find approximate values for A and b. Explain how you arrived at your answer.



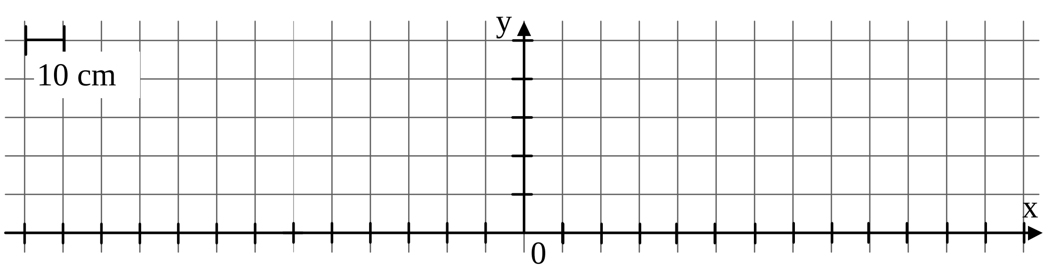
3. Predict the maximum amplitude of the wavepulse after its peak has moved a distance 3b to the right. Explain how you arrived at your answer.

4. On your computer, open the movie ***pulse.mov***. Play the video. Compare what you see in the video to your answer to question 3. Resolve any discrepancies.

5. Describe what the symbol "x" represents in this problem. Explain.

B. Consider a wavepulse propagating to the right along an ideal spring. The shape of the spring at time t = 0 seconds is given by $y(x) = \dfrac{50cm}{\left(x/b\right)^2 + 1}$, b = 20 cm.

1. In the space below, sketch the shape of the spring after the wavepulse has moved so that its peak is at x = 70 cm. Compare this graph to the graph you sketched in question 1 on the previous page.



2. On the graph above, draw a coordinate system with its vertical axis at 70 cm. Label its horizontal axis with the variable *s*.

3. Write a formula y(s) that describes the displacement of any piece of the spring (when the peak of the wavepulse is located at 70 cm) *as a function of s*. Explain.

4. Write an equation for *s* as a function of *x*.

5. Write a formula that describes the shape of the wavepulse at the time it is centered at 70 cm *as a function of x*. Explain.

6. Consider that the wavepulse had moved an arbitrary distance x_0. How would your formula change? Explain.

7. Suppose the wavepulse moved a distance x_0 at a speed v in a time t_0. Write an equation for x_0 in terms of v and t_0.

8. How could you use this information to find the displacement of any piece of the spring at time t_0? Write an equation that would let you do this. Explain.

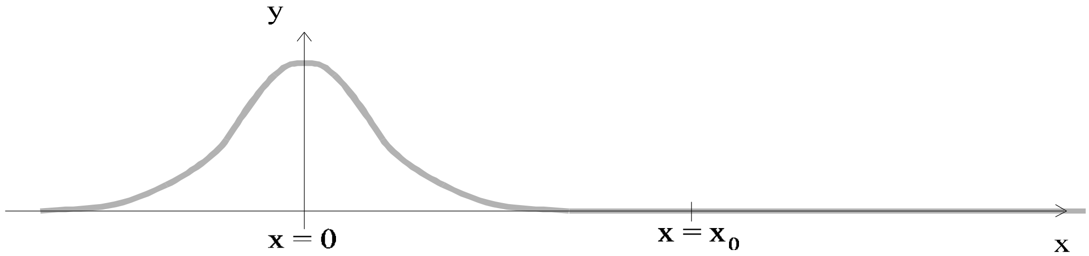
9. Write an equation that describes the displacement of any piece of the spring at *any* time. Explain.

10. Describe how you would find the displacement of any piece of the spring at any time.

11. Would your equation in question 8 be correct if the spring were *not* ideal, or if there were friction between the spring and the ground? Explain.

II. Measuring the Shape of the Wavepulse

A. Consider a different wavepulse propagating along a long, taut spring. The diagram below shows the shape of the wavepulse at time t = 0 sec. Suppose the displacement of the spring at various values of x is given by $y(x) = Ae^{-\left(x/b\right)^2}$. The wavepulse moves with a velocity *v* to the right.



1. On the diagram above, sketch the shape of the spring after it has traveled a distance x_0, where x_0 is shown in the figure. Explain why you sketched the shape you did.

2. Write an equation that describes the displacement of the spring as a function of x and t for the instant of time that you have sketched. Explain how you determined your answer.

A piece of tape is attached to the spring at position x = x_0.

3. In the space below, *qualitatively* sketch the velocity of the piece of tape as a function of time. Explain how you arrived at your answer.

4. In the space below, *qualitatively* sketch the acceleration of the piece of tape as a function of time. Explain how you arrived at your answer.

B. On your computer, play ***pulse.vpt*** to show a video of a single wavepulse traveling along a spring. Suppose the wavepulse in the video can be described by an equation like the one you wrote in question 2 on the previous page.

1. What effect would changing the parameters "A," "b," and "v" in the equation (from page 4) have on the wavepulse?

2. Find numerical values for each parameter in the equation. Show all work.

3. Use your equation to find the displacement of the spring at position x = 125 cm at time t = 0.1 sec. Show all work.

4. Advance the video 0.1 sec beyond the instant of time where its peak is located at the origin. Find the displacement of the spring at position x = 125 cm and time t = 0.1 sec.

5. Compare your answer to question 4 with your answer to question 3. Resolve any discrepancies.

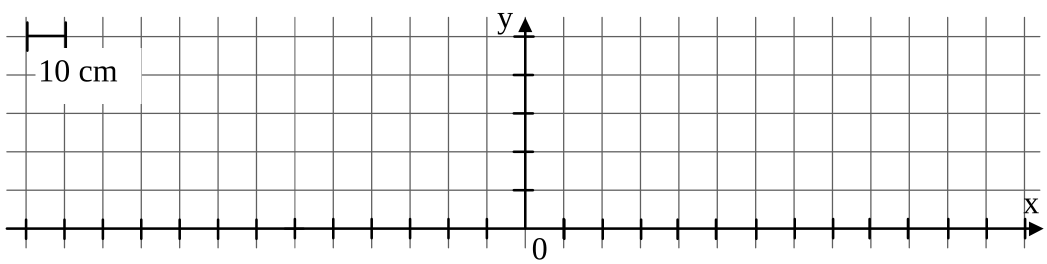
Name **Tutorial Homework**

Suppose a pulse is propagating along a spring with a velocity 600 cm/sec *to the left*. At time t = 0 sec, the displacement of the spring from its equilibrium position can be written as a function of x, $y(x) = \frac{50cm}{(x/b)^2 + 1}$, where b = 20 cm.

1. Write an equation that describes the displacement of the spring from its equilibrium position at any position, x, and at any time, t. Explain how you arrived at this answer.

2. Compare your equation to the equation which you derived in section I.B, question 9 of the tutorial. What has changed? Explain the effect of this change.

3. In the space below, graph the displacement of the spring after 0.1 seconds have passed.



4. Compare the shape of the graph you have sketched to the equation you wrote in question 1. Find the displacement of a point located 20 cm to the left of the peak of the pulse after 0.1 seconds have passed.

5. What point had this same displacement at time t = 0 seconds? Explain how you arrived at your answer.

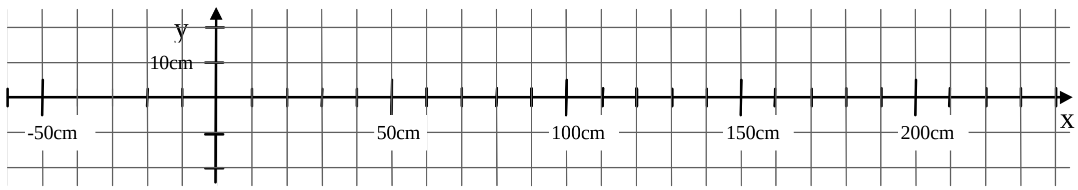
Mathematical Description of Waves - Tutorial Homework

Bridging Problem

Consider a pulse traveling *to the right* with a speed of 600 cm/sec. The equation describing the displacement of the spring from equilibrium at time t = 0 sec is

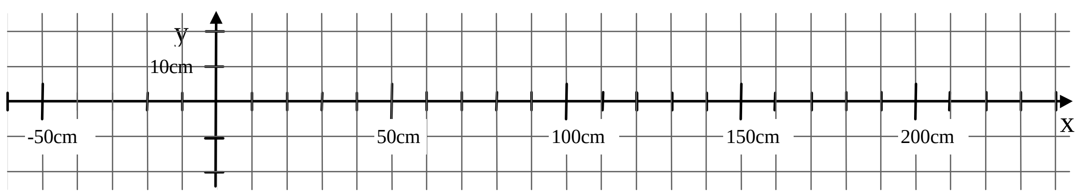
$y_1(x) = A_1 e^{-\left(\frac{x}{b_1}\right)^2}$, where A_1 = 20 cm and b_1 = 20 cm.

a) Sketch the shape of the spring at time t = 0 sec in the graph below. Use the indicated scale.



b) Write an equation that describes the displacement of any piece of the spring at any time for this pulse. Explain how you arrived at this answer.

c) Now suppose a second pulse moving *to the left* is also present on the spring. At t = 0.1 sec the equation describing this 2nd pulse is $y_2(x) = A_2 e^{-\left(\frac{x-200cm}{b_2}\right)^2}$ where A_2 = 10 cm and b_2 = 10 cm. Sketch the shape of the spring at time t = 0.1 sec in the graph below, labeling the pulse going to the right “1” and the pulse going to the left “2.”



d) At what time and position do the maxima of the two pulses meet? Show your work.

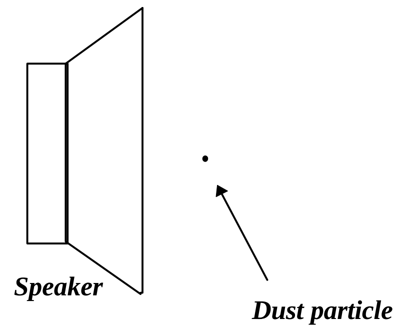
e) Write an equation that describes the shape of the spring when the maxima meet. Show your work.

Appendix C: Sound Waves Tutorial

Name

Pretest

1. Consider a small piece of dust placed in front of a large, silent loudspeaker (see figure).



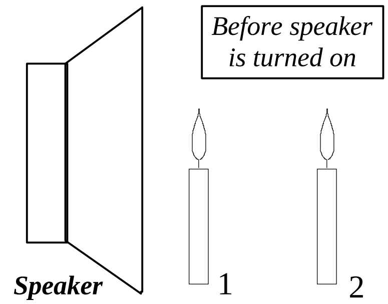
A. The speaker is turned on and plays a note with a constant frequency, *f*. How, if at all, does this affect the motion of the dust particle. Explain.

B. Consider an identical dust particle placed in front of an identical loudspeaker. The speaker is turned on and plays a note with frequency *2f*. How, if at all, does this affect the motion of the dust particle. Explain. Compare your answer to your answer to question A.

C. Consider an identical dust particle placed in front of an identical loudspeaker. The speaker is turned on and plays a note at the original frequency, *f*, but with a higher volume. How, if at all, does this affect the motion of the dust particle. Explain. Compare your answer to your answer to question A.

(over)

2. Consider two lit candles placed in front of a silent loudspeaker (see figure). The candle flames, flame 1 and flame 2, are perfectly upright and still.



A. The speaker is turned on and plays a note at a constant frequency, *f*. How, if at all, does this affect the motion of *flame 1*? If it does not move, state so explicitly.

B. Compare the motion, if any, of *flame 1* and *flame 2* after the loudspeaker is turned on. Explain how you arrived at your answer. If neither moves, state so explicitly.

C. Consider a situation where the speaker plays a note with the frequency *2f*. Compare the motion, if any, of *flame 1* and *flame 2*. Explain how you arrived at your answer. If neither moves, state so explicitly.

p. 2

Sound Waves

I. Introduction

Last week we investigated propagating waves on springs. This week, we will consider sound waves. Experiments show that sound waves travel at about 340 m/s through air at room temperature.

Consider a flame placed in front of a speaker as shown in the figure at right. No wind is blowing.

A. The speaker plays a note at a constant pitch. Explain how, if at all, the sound produced by the speaker affects the flame. If the sound does not affect the flame, state that explicitly.

B. Open the movie ***Sound Movie.mov*** on your desktop. Play the movie.

1. Describe your observations. Do your observations agree with your earlier predictions?

2. How can you account for the flame's motion? Explain your reasoning.

Consider a dust particle in front of a silent loudspeaker. The dust particle is in the same location as the original location of the flame.

3. The speaker is turned on and plays a note with a constant frequency, *f*. How, if at all, does this affect the motion of the dust particle? Explain.

II. Motion of a Single Flame

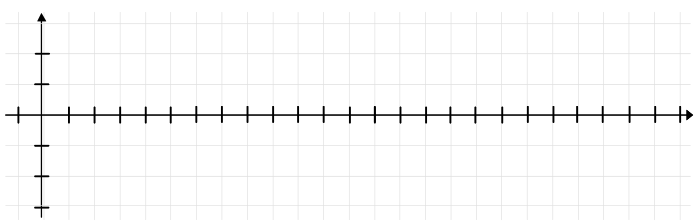
A. The program VideoPoint lets you analyze the motion of the flame by giving information about the positions of points on the screen at different times. On the desktop, open the file ***Sound Data File.vpt***. This lets you analyze the position of points on the video screen for the movie. Play the video using the single advance buttons.

1. What is the red cross on the video screen measuring? Explain.

2. The "Table" window of ***Sound Data File.vpt*** includes data already obtained. These data are also shown to the right. What does this data represent?

Time (s)	x position (mm)	y position (mm)
0	0	0
0.03333	2.8	0
0.06667	2.1	0
0.1	0	0
0.1333	-3.5	0
0.1667	-1.4	0
0.2	1.4	0
0.2333	2.8	0
0.2667	2.1	0
0.3	-2.1	0
0.3333	-3.5	0
0.3667	-1.4	0
0.4	2.1	0
0.4333	2.8	0
0.4667	-2.1	0
0.5	-3.5	0
0.5333	-1.4	0
0.5667	2.1	0
0.6	3.5	0
0.6333	2.1	0
0.6667	-2.1	0
0.7	-2.1	0

3. In the space below, plot the position of the flame.



What does each axis on your graph represent? Explain.

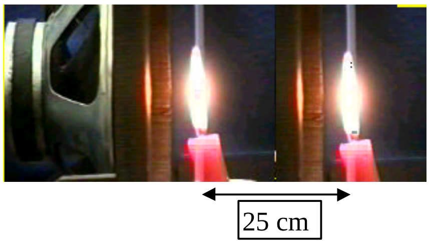
4. Describe the shape of your graph. (It may help to sketch a continuous curve on the basis of your data points.)

B. Find the period with which the flame and speaker oscillate. Explain how you obtained your answer.

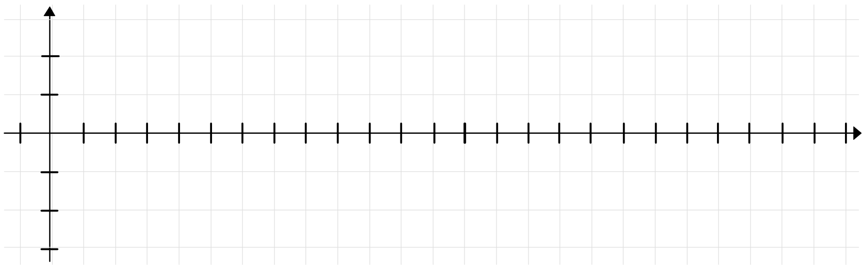
C. How many oscillations are there in a 1 second time interval. Explain how you obtained the answer.

III. Motion of Many Flames

A. Consider two candles sitting 25 cm apart in front of a loudspeaker oscillating at 680 Hz. A clock is started at an arbitrary time. At time t = 0 seconds, the first flame is perfectly vertical and moving away from the speaker. Its maximum displacement from equilibrium is 5 mm.



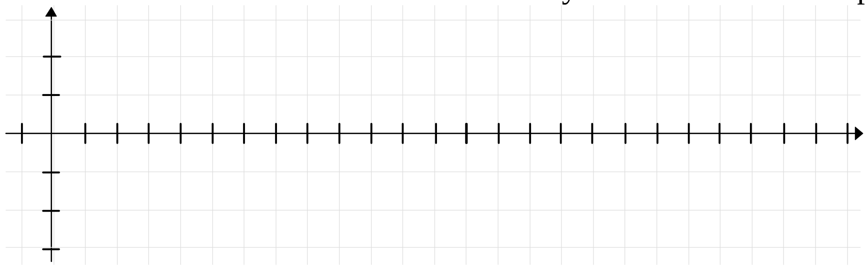
1. In the graph below, sketch the displacement of the first flame from equilibrium at different times. Label axes clearly. Explain how you arrived at your answer.



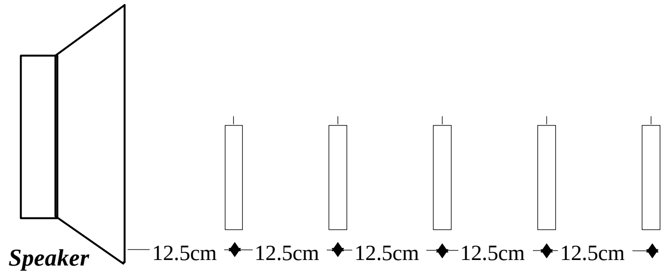
2. Compare the graph above to the graph you plotted on page 2. Explain.

3. Compare the motion of the second flame to the motion of the first flame. Explain.

4. In the graph below, sketch the displacement of the second flame for the entire time considered. Describe in words how you determined the shape of the sketch.

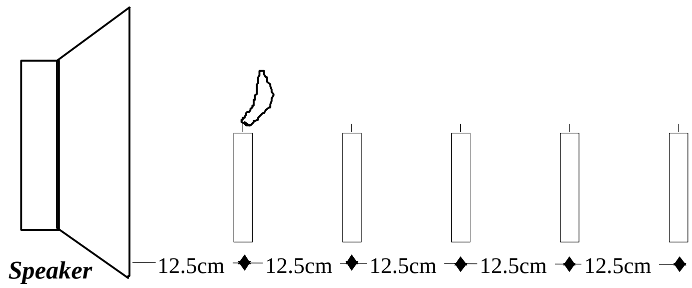


B. Consider an arrangement of candles where each candle is placed 12.5 cm from its nearest neighbor, and the first is located 12.5 cm from the speaker. The speaker plays a note at 680 Hz. At an arbitrary time after all the flames are in motion, a clock is started. At time t = 0 seconds, the first flame is at its maximum displacement of 5 mm from its upright position, away from the loudspeaker.

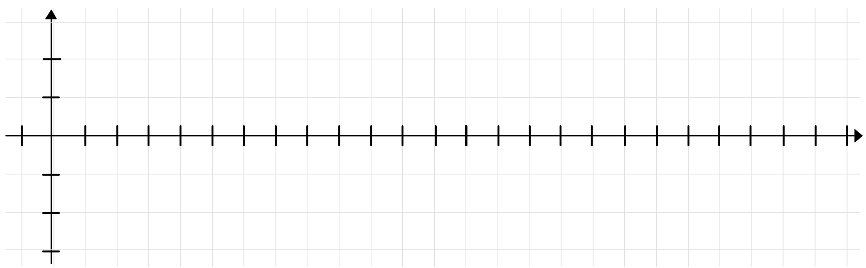


1. How would the graph of displacement vs. time for the second flame compare to the same graph for the first flame? Explain your reasoning.

2. The displacement of flame 1 at time t = 0 seconds is at a maximum and is shown at right. (The displacement is exaggerated for easy viewing). Sketch the displacement of each of the other flames at time t = 0 seconds in the diagram. Explain how you arrived at your answer.



3. In the graph below, sketch the displacement of each flame vs. the distance of the flame with respect to the speaker at time t = 0 seconds. Let each block on the horizontal axis represent 2.5 cm. Label axes clearly.



4. Consider a very large number of flames placed from 5 cm to 60 cm away from the speaker. On the graph on the previous page, plot the displacement of each of these flames at time t = 0 seconds as a function of distance from the speaker. Explain how you arrived at your answer.

5. Describe the shape of the graph you have sketched.

6. How can you use the graph you have sketched to find the wavelength of the sound produced by the loudspeaker? Explain.

7. Find the wavelength of the sound produced by the speaker in the movie ***sound.mov***.

VI. Comparing Graphs

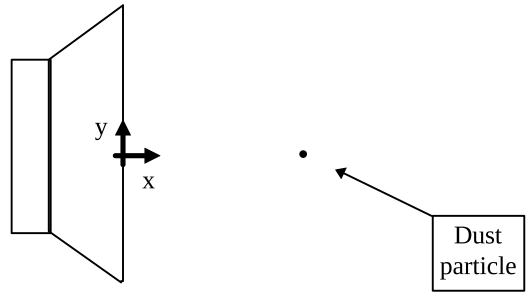
1. How could you use the graph on page 2 (instead of the graph on page 4) to find the wavelength of the sound wave?

2. How could you use the graph on page 4 (instead of the graph on page 2) to find the frequency of the sound wave? the period of the sound wave?

3. How could you use the graphs on pages 2 and 4 to find the amplitude of the sound wave?

Name **Tutorial Homework**

Consider a single dust particle floating a distance x_0 from a loudspeaker (see figure). The loudspeaker is turned on and produces a sound with a constant frequency *f*. The speed of sound is *v*. In the indicated coordinate system, the origin is located at the center of the speaker.



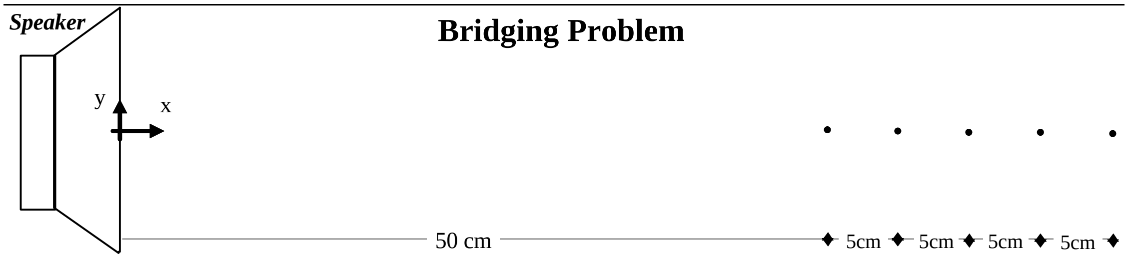
1. How long does it take for the sound wave to reach the dust particle? Explain.

2. At time t = 0 sec, the dust particle begins to move away from the loudspeaker. Write an equation that describes the displacement of the dust particle from equilibrium for all times after t = 0 sec. Explain how you arrived at your answer. Explicitly define any variables you introduce in your equation.

3. Consider an identical dust particle a distance x_0 from an identical loudspeaker. The loudspeaker is turned on and produces a sound with a frequency of *2f*. Does the dust particle begin to move earlier than in question 1? Explain.

4. Write an equation that describes the displacement of the dust particle in question 3 from equilibrium for all times after t = 0 sec. Explain how you arrived at your answer.

Bridging Problem

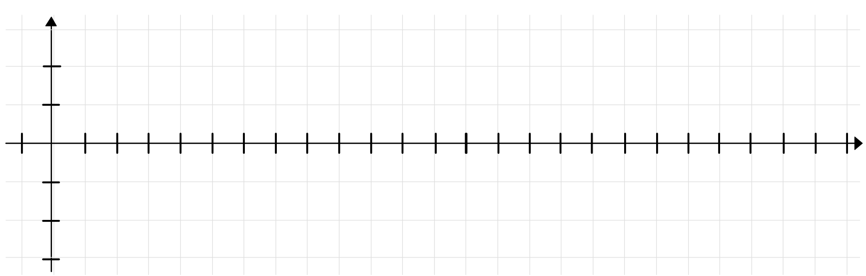


Five dust particles are placed in a row 5 cm apart beginning 50 cm from a loudspeaker (see figure). The speaker plays a note with a frequency of 1700 Hz. The speed of sound is 340 m/s. The maximum displacement of the first dust particle is s_{max} = 3 mm. Assume that the intensity of the sound wave is the same for all dust particles. In the indicated coordinate system, the origin is at the center of the loudspeaker. A clock is started at an arbitrary time.

a) At time t = 0 sec, the first dust particle is at equilibrium and moving away from the loudspeaker. Find t_0, the amount of time that elapses until the second dust particle is at its equilibrium position. Explain.

b) What is the displacement from equilibrium of the first dust particle at time t_0? Explain how you arrived at your answer.

c) In the graph below, sketch a graph of s vs. x at time t_0. Define each axis clearly.



d) Find s(x,t) for x = 65 cm and t = 2.941176 x 10^{-4} sec. Show all work.

Appendix D-1: Wave Diagnostic Test, Preliminary Version

University of Maryland
Department of Physics

Spring 1997 Post Wave Test v.3

Name Class Section

Introduction: The Physics Education Research Group is studying how student learn physics in introductory courses. We are developing new methods and new materials like the tutorials for teaching physics.

Request: As you answer these questions, we want to focus on how you respond and how you approach the questions. In order for us to evaluate your responses in more detail, we would like to videotape you answering these questions. The tapes will be transcribed for the group to study.

Confidentiality: These tapes will be edited and transcribed with code names. Your name will be kept confidential.

Grades: Your grade in this course will not be affected in any way by whether you choose to participate or by what you say on tape.

Value: The better we understand what is happening in class and know how you are thinking about physics, the more effectively we can teach you. It also helps us to develop better ways of teaching physics.

If you are willing to allow us to tape you, please write your name, student number, and signature in the space below.

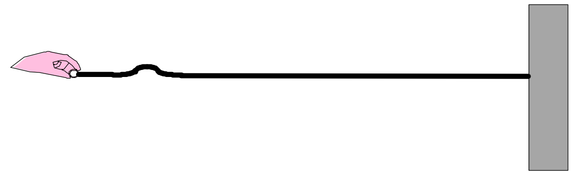
Name____________________________________

Student Number____________________

Signature_________________________________

UMd Wave Diagnostic Test

1. A person holds a long, taut string and quickly moves her hand up and down, creating a pulse which moves toward the wall to which the string is attached and reaches it in a time t_0 (see figure).



How could the person *increase* the amount of time it takes for the pulse to reach the wall? Explain.

2. Consider a pulse propagating along a long, taut string in the +x-direction. The diagram below shows the shape of the pulse at t = 0 sec. Suppose the displacement of the string at t = 0 sec for different values of x is given by $y(x) = Ae^{-(x/b)^2}$.

a) On the diagram, sketch the shape of the string after the pulse has traveled a distance x_0, where x_0 is shown in the figure. Explain why you sketched the shape as you did.

b) For the instant of time that you have sketched, write an equation for the displacement of the string as a function of x. Explain how you determined your answer.

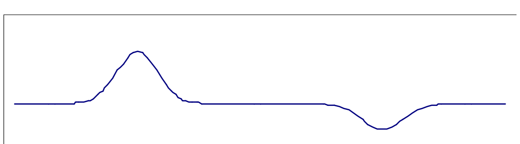
Please note:

For the remaining multiple-choice questions, please answer in the indicated spaces.

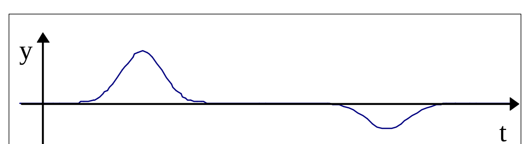
On some questions, more than one answer may be correct (i.e. *b*, *c* and *d* from a list of possible responses *a*-*k*). If so, **give them all**.

In some sections, you may use the same response **more than once** to answer different questions (i.e. use *d* to answer questions 14, 15, and 18).

For some questions, answers may describe both pictures and graphs. For example:



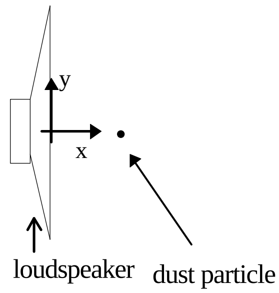
A picture of two wavepulses on a string



A graph of displacement as a function of time

In each case, the same diagram can be used to represent different quantities.

For **questions 1 to 4** consider the following situation. A dust particle is located a distance x_0 from the front of a silent loudspeaker (see figure). The loudspeaker is turned on and plays a note at a constant pitch. At time t = 0, the particle begins to move.



1. Which of the actions *a-f* to the right describes the motion of the dust particle after time t = 0 sec. More than one answer may be correct. If so, **give them all.** _______ Explain your reasoning.

Possible Responses for question 1:

a) The dust particle will move up and down.
b) The dust particle will be pushed away from the speaker.
c) The dust particle will move side to side.
d) The dust particle will not move at all.
e) The dust particle will move in a circular path.
f) None of these answers is correct.

2. Consider the coordinate system shown in the figure. Which equation *a-i* best describes the position of the dust particle for all times t > 0? _______
Explain how the equation you chose relates to the motion you described (be sure to include a description or definition of **all** variables, such as A, ω, k, or s). If you chose "*i*," explain.

Possible Responses for question 2:

a) $x = A\sin(\omega t)$ b) $y = A\sin(\omega t)$
c) $s = x_0 + v/t$ d) $s = A\sin(kx)$
e) $y = A\sin(kx - \omega t)$ f) $x = x_0 - v/t$
g) $x = A\sin(kx)$ h) $s = A\sin(\omega t)$
i) none of the above

Use possible responses *a-e* to the right to answer the following two questions. You may use the same response more than once. More than one answer may be correct. If so, **give them all.**

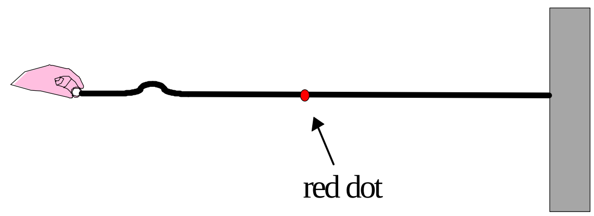
3. How, if at all, would the answer to question 1 change if the speaker played a note at a higher pitch? ________ Explain.

4. How, if at all, would your answer to question 1 change if the speaker played a note at a greater volume (but the original pitch)? ________ Explain.

Possible changes to your answer to question 1:

a) The particle would move exactly as before.
b) The particle would move slower.
c) The particle would move faster.
d) The particle would move with a greater amplitude.
e) The particle would still not move at all

For **questions 5 to 8**, consider the following situation. A long, taut string is attached to a distant wall (see figure). A demonstrator moves her hand and creates a very small amplitude pulse which reaches the wall in a time t_0. A small red dot is painted on the string halfway between the demonstrator's hand and the wall. For each question, state which of the actions *a–k* (listed to the right) **taken by itself** will produce the desired result. For each question, more than one answer may be correct. If so, **give them all.**



How, if at all, can the demonstrator repeat the original experiment to produce:

5. A pulse that takes a longer time to reach the wall. More than one answer may be correct. If so, **give them all.**__________ Explain.

6. A pulse that is wider than the original pulse. More than one answer may be correct. If so, **give them all.**__________ Explain.

7. A pulse that makes the red dot stay in motion for less time than in the original experiment. More than one answer may be correct. If so, **give them all.**__________ Explain.

8. A pulse that makes the red dot travel a further distance than in the original experiment. More than one answer may be correct. If so, **give them all.**__________ Explain.

Possible Responses for questions 5 to 8:

a) Move her hand more quickly (but still only up and down once and still by the same amount).

b) Move her hand more slowly (but still only

c) up and down once and still by the same amount).

d) Move her hand a larger distance but up and down in the same amount of time.

e) Move her hand a smaller distance but up and down in the same amount of time.

f) Use a heavier string of the same length, under the same tension

g) Use a lighter string of the same length, under the same tension

h) Use a string of the same density, but decrease the tension.

i) Use a string of the same density, but increase the tension.

j) Put more force into the wave.

k) Put less force into the wave.

l) none of the above.

For **questions 9 to 10**, consider the following situation. A pulse on a string described at time t = 0 s by the equation $y(x) = Ae^{-(x/b)^2}$ propagates along a long, taut string in the +x-direction. The diagram above shows the string at t = 0 s.

9) On the diagram, **sketch the shape of the string** after the pulse has traveled a distance x_0, where x_0 is shown in the figure. Which of statements *a-h* to the right describes the shape you have drawn. More than one response may be correct. If so, give them all. ____________ Explain.

Possible Responses for question 9:

a) The pulse will have a smaller amplitude.
b) The pulse will have a larger amplitude
c) The pulse will be narrower.
d) The pulse will be wider.
e) The pulse will have a bigger area.
f) The pulse will have a smaller area.
g) The pulse will have the same shape as before.
h) None of these answers is correct.

10) Which of the equations *a-h* to the right gives an equation that gives the displacement of the string as a function of x at the instant in time that you have sketched. ____________. Explain how you determined your answer.

Possible Responses for question 10:

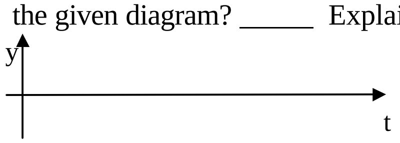
a) $y(x) = Ae^{-(x_0/b)^2}$ b) $y(x) = Ae^{-(x/b)^2}$
c) $x = b\sqrt{\ln(y)}$ d) $x_0 = vt$
e) $x = -b\sqrt{\ln y}$ f) $y(x) = Ae^{-(x-x_0/b)^2}$
g) none of the above

For **questions 11 to 15**, consider the following situation. Two wavepulses with different amplitudes on a string are moving at speed v = 1 m/s toward each other. **At time t = 0.5 sec**, the shape of the string is shown in the diagram to the right, and the wavepulses are separated by a distance of 1 m. Three specific pieces of string are labeled "p," "q," and "r." In answering these questions, you may use the same answer more than once. In each diagram, up is positive.

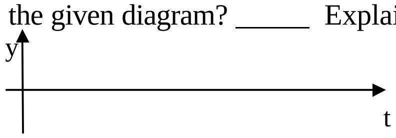
11. Which diagram represents a picture of the string at time t = 1.0 s (i.e. 0.5 s after the time in the given diagram)? ______ Explain.

12. Which diagram represents a picture of the string at time t = 1.5 s (i.e. 1.0 s after the time in the given diagram)? ______ Explain.

13. Which diagram represents a plot of the displacement (as a function of time) of the piece of string indicated by a "p" in the given diagram? ______ Explain.



14. Which diagram represents a graph of the displacement (as a function of time) of the piece of string indicated by a "q" in the given diagram? ______ Explain.



15. Which diagram represents a graph of the displacement (as a function of time) of the piece of string indicated by an "r" in the given diagram? ______ Explain.

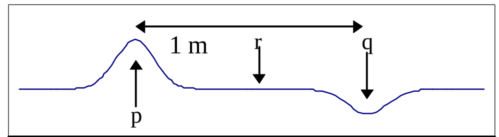
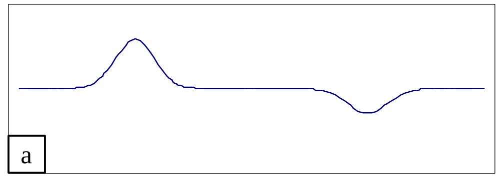
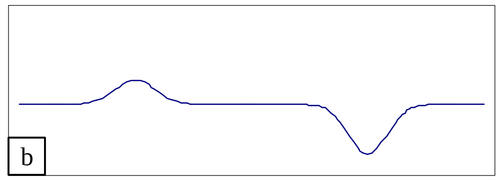
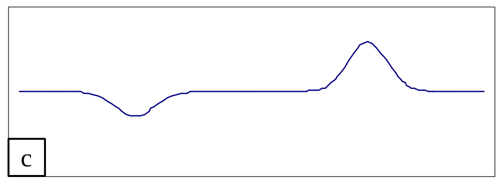
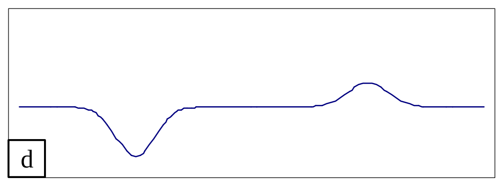


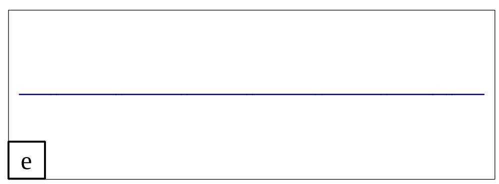
Diagram of string at time t = 0.5 sec

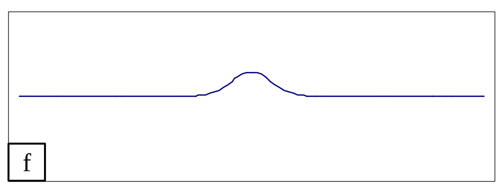


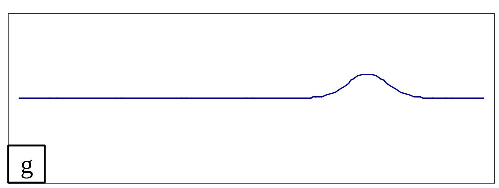












h) none of the above are correct.

For **questions 16 to 19**, consider the following situation. Two asymmetric wavepulses on a string are moving at speed v = 1 m/s toward each other. **At time t = 0.4 s**, the shape of the string is shown in the diagram to the right, and the peaks of the pulses are separated by a distance 1.2 m. One piece of string is labeled "p." In answering these questions, you may use the same answer more than once. If you choose "h," explain.

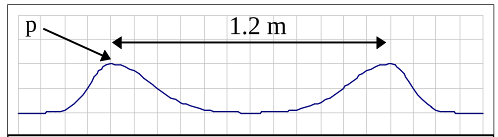


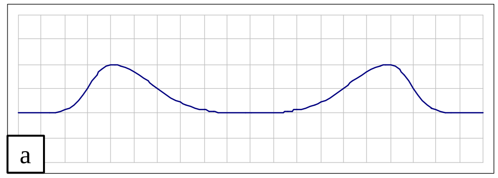
Diagram of string at time t = 0.4 sec

16. Which of the diagrams represents a picture of the string at time 1.0 s (0.6 s after the time in the given diagram)? ______ Explain.

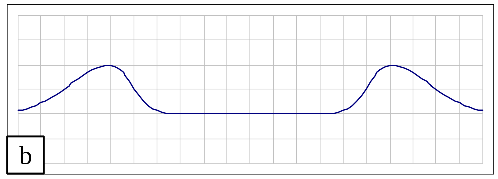
17. Which of the diagrams represents a picture of the string at time *a little bit before* time t = 1.0 s (e.g. t = 0.9 s, 0.5 s after the time in the given diagram)? ______ Explain.

18. Which of the diagrams represents a picture of the string at time t = 1.6 s (1.2 s after the time in the given diagram)? ______ Explain.

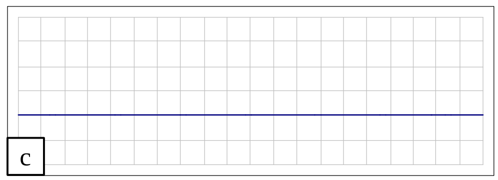
19. Which of the diagrams represents a graph of the displacement (as a function of time) of the piece of string indicated by a "p" in the given diagram? ______ Explain.



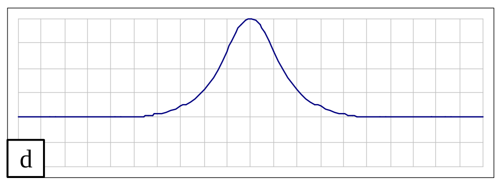
a



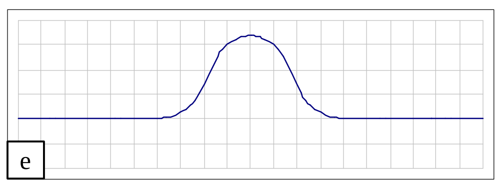
b



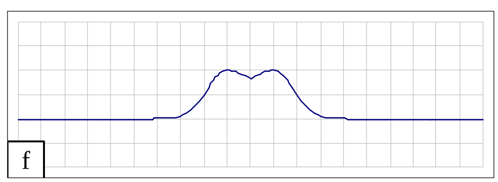
c



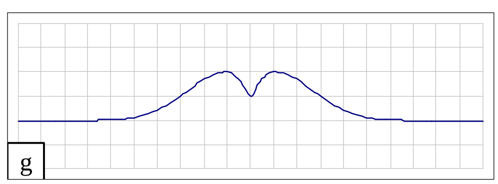
d



e



f



g

h) none of the above are correct.

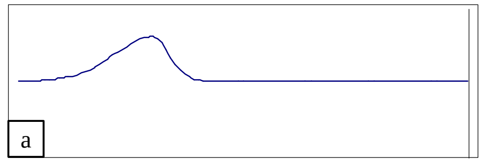
For **questions 20 to 23**, consider the following situation. An asymmetric wavepulse moves on a string at speed 1 m/s toward a pole. At time t = 0 s, the shape of the string is shown in diagram “a,” and the peak of the wavepulse is a distance 1 m from the pole. In answering these questions, you may use the same answer more than once.

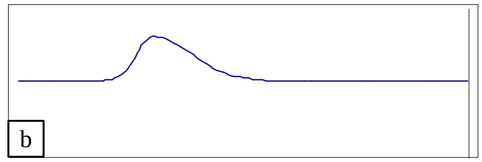
20. If the string is firmly attached to the pole, which diagram represents a picture of the string at time t = 1 s? ______
    Explain.

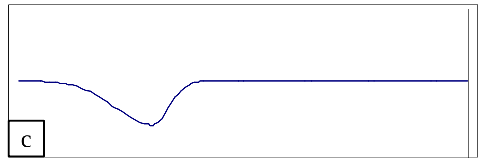
21. If the string is free to move along the pole, which diagram represents a picture of the string at time t = 1 s? ______
    Explain.

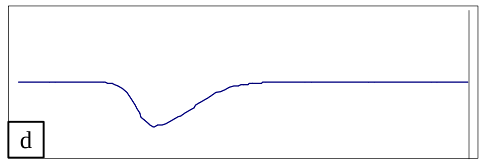
22. If the string is firmly attached to the pole, which diagram represents a picture of the string at time t = 2 s? ______
    Explain.

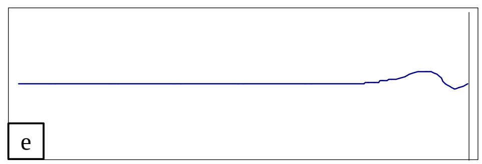
23. If the string is free to move along the pole, which diagram represents a picture of the string at time t = 2 s? ______
    Explain.

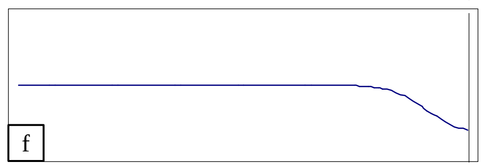

a

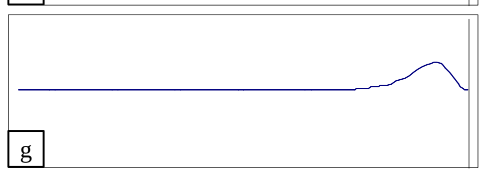

b

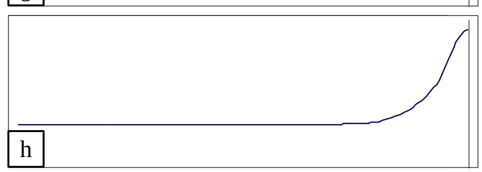

c

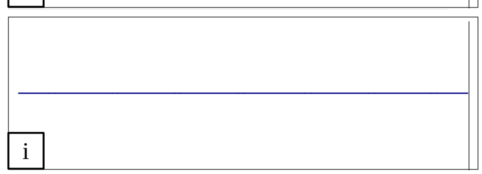

d


e


f

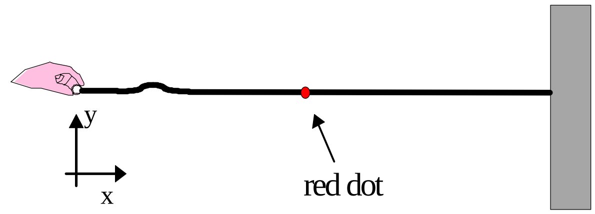

g

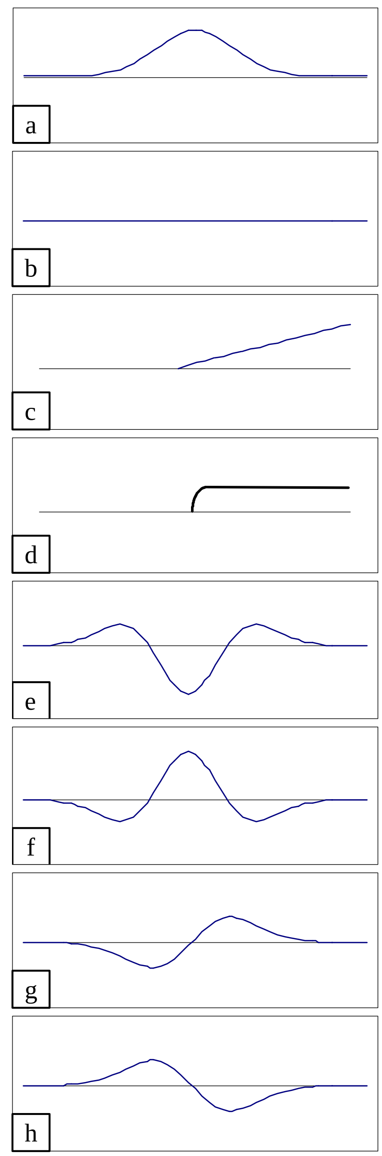

h


i

j) none of the above

For **questions 24 to 28**, consider the following situation. A pulse with a shape as shown in diagram "a" to the right is traveling to the right along a string on which a red dot of paint is located (see figure). Consider only the time until the pulse reaches the wall. For each question, identify which figure below would look most like the described quantity. For each graph, consider positive to be up. If none of the figures look like you expect the graph to look, answer "i." In responding to these questions, you may use the same answer more than once.





i) None of these figures is correct.

24. The graph of the y displacement of the red dot as a function of time. __________ Explain.

25. The graph of the x displacement of the red dot as a function of time. __________ Explain.

26. The graph of the y velocity of the red dot as a function of time. __________ Explain.

27. The graph of the x velocity of the red dot as a function of time. __________ Explain.

28. The graph of the y component of the force on the red dot as a function of time. _________ Explain.

Appendix D-2: Wave Diagnostic Test, Final Version, Pre-Instruction

Name **UMd Wave Diagnostic Test**

1. Michael and Laura are standing 100 m apart and yell "Yo!" at each other at exactly the same instant. Michael yells louder than Laura, and the pitch (frequency) of his voice is lower.

Will Laura hear Michael first, Michael hear Laura first, or will they hear each other at the same time? Explain how you arrived at your answer.

How, if at all, would your answer change if Laura yelled at the same volume as Michael? Explain your reasoning.

How, if at all, would your answer to the original question change if Michael and Laura yelled at the same pitch but Michael yelled louder? Explain your reasoning.

2. Consider two wavepulses with different amplitudes moving on a string at speed of 10 m/s toward each other. **At time t = 0 sec**, the shape of the string is shown in the diagram to the right, and the wavepulses are separated by a distance of 1 m.

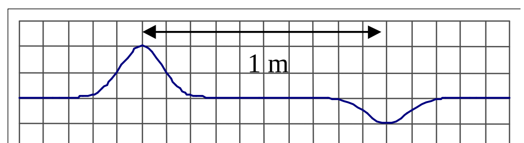
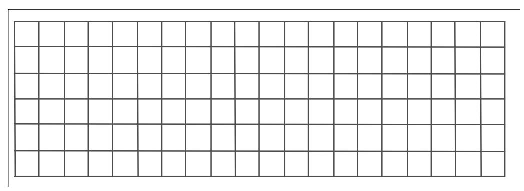
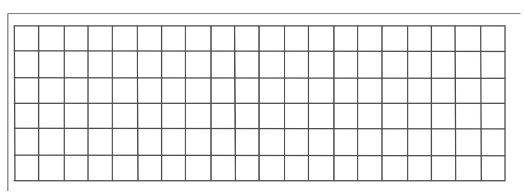


Diagram of string at time t = 0 sec

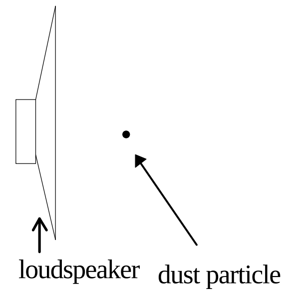
Sketch the shape of the string at time t = 0.05 sec in the diagram to the right. Explain how you arrived at your answer.



Sketch the shape of the string at time t = 0.1 sec in the diagram to the right. Explain how you arrived at your answer.



3. A dust particle is located in front of a silent loudspeaker (see figure). The loudspeaker is turned on and plays a note at a constant pitch.

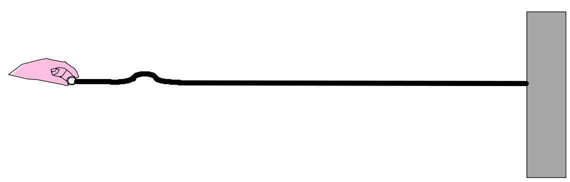


Describe the motion of the dust particle. Explain your reasoning.

How, if at all, would your answer change if the speaker played a note at a higher pitch (frequency)? Explain your reasoning.

How, if at all, would your answer to the original question change if the speaker played a note at a greater volume (but the original pitch)? Explain.

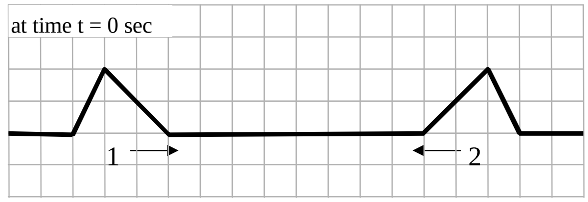
4. A person holds a long, taut string and quickly moves her hand up and down, creating a pulse which moves toward the wall to which the string is attached. The pulse reaches the wall in a time t_0 (see figure).



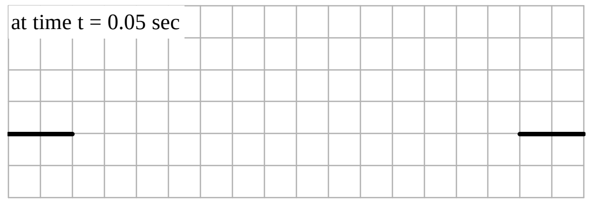
How could the person decrease the amount of time it takes for the pulse to reach the wall? Explain.

How, if at all, would the *speed* of the pulse change if the pulse were wider? Explain your reasoning.

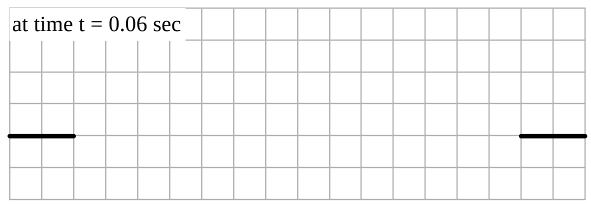
5. Consider two pulses on a spring, as shown in the figure to the right. They are moving toward each other at 100 cm/sec. Each block in the picture represents 1 cm.



In the figure to the right, sketch the shape of the spring after 0.05 sec have elapsed. Explain how you arrived at your answer.



In the figure to the right, sketch the shape of the spring after 0.06 sec have elapsed. Explain how you arrived at your answer.



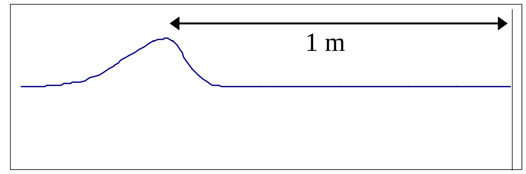
In the figure to the right, sketch the shape of the spring after 0.1 sec have elapsed. Explain how you arrived at your answer.

6. Margaret stands 20 m from a large wall and claps her hands together once. A short moment later, she hears an echo.

How, if at all, would the time it takes for her to hear the echo change if she clapped her hands harder? Explain.

Consider a dust particle floating in the air very close to the wall (within 0.1 mm). Describe the motion, if any, of this dust particle between the moment that Margaret claps and the moment she hears the echo. Explain how you arrived at your answer.

7. An asymmetric wavepulse moves on a string toward a pole at speed 10 m/s. At time t = 0 sec, the shape of the string is shown in the diagram to the right and the peak of the wavepulse is a distance 1 m from the pole.



Consider that the string is **firmly attached** to the pole.

In the figure to the right, sketch the shape of the string at time t = 0.1 sec. Explain how you arrived at your answer.

In the figure to the right, sketch the shape of the string at time t = 0.2 sec. Explain how you arrived at your answer.

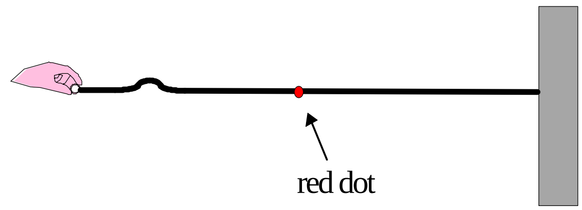
8. Consider that the experiment above (in question 7) is repeated, but the string shown in the figure is **free to move** along the pole to which it is attached.

In the figure to the right, sketch the shape of the string at time t = 0.1 sec. Explain how you arrived at your answer.

In the figure to the right, sketch the shape of the string at time t = 0.2 sec. Explain how you arrived at your answer.

After completing these questions, please turn in this part of the questionnaire. Then, get the last page of the questionnaire…

9. A long, taut string is attached to a distant wall (see figure). A demonstrator moves her hand and creates a very small amplitude pulse which reaches the wall in a time t_0. A small red dot is painted on the string halfway between the demonstrator's hand and the wall. For each question, state which of the actions *a–k* (listed to the right) **taken by itself** will produce the desired result. For each question, more than one answer may be correct. If so, **give them all.**



How, if at all, can the demonstrator repeat the original experiment to produce:

A pulse that takes a longer time to reach the wall. More than one answer may be correct. If so, **give them all.**__________ Explain.

A pulse that is wider than the original pulse. More than one answer may be correct. If so, **give them all.**__________ Explain.

A pulse that makes the red dot stay in motion for less time than in the original experiment. More than one answer may be correct. If so, **give them all.**__________ Explain.

A pulse that makes the red dot travel a further distance than in the original experiment. More than one answer may be correct. If so, **give them all.**__________ Explain.

Possible responses for all parts of question 9:

a) Move her hand more quickly (but still only up and down once and still by the same amount).

b) Move her hand more slowly (but still only up and down once and still by the same amount).

c) Move her hand a larger distance but up and down in the same amount of time.

d) Move her hand a smaller distance but up and down in the same amount of time.

e) Use a heavier string of the same length, under the same tension

f) Use a lighter string of the same length, under the same tension

g) Use a string of the same density, but decrease the tension.

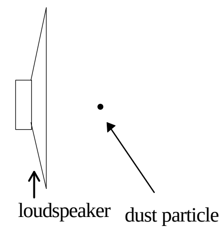
h) Use a string of the same density, but increase the tension.

i) Put more force into the wave.

j) Put less force into the wave.

k) none of the above.

10. A dust particle is located in front of a silent loudspeaker (see figure). The loudspeaker is turned on and plays a note at a constant (low) pitch. **Which choice or combination of the choices** *a*-*f* (listed below) can describe the motion of the dust particle after the loudspeaker is turned on? **Circle the correct letter or letters.** Explain.

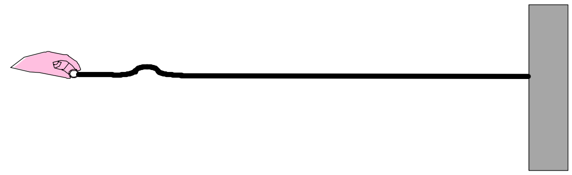


Possible responses for question 10:
a) The dust particle will move up and down.
b) The dust particle will be pushed away from the speaker.
c) The dust particle will move side to side.
d) The dust particle will not move at all.
e) The dust particle will move in a circular path.
f) None of these answers is correct.

Appendix D-3: Wave Diagnostic Test, Final Version, Post-Instruction

Name **UMd Wave Diagnostic Test**

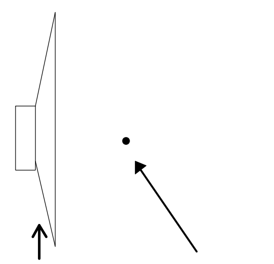
1. A person holds a long, taut string and quickly moves her hand up and down, creating a pulse which moves toward the wall to which the string is attached. The pulse reaches the wall in a time t_0 (see figure).



How could the person decrease the amount of time it takes for the pulse to reach the wall? Explain.

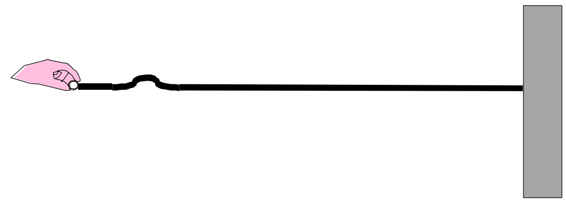
2. A dust particle is located in front of a silent loudspeaker (see figure). The loudspeaker is turned on and plays a note at a constant pitch.

Describe the motion of the dust particle. Explain your reasoning.



After completing these questions, please turn in this part of the questionnaire. Then, get the last page of the questionnaire…

3. A long, taut string is attached to a distant wall (see figure). A demonstrator moves her hand up and down exactly once and creates a very small amplitude pulse which reaches the wall in a time t_0. For the question below, state which of the actions *a–k* (listed to the right) **taken by itself** will produce the desired result. Note that more than one answer may be correct. If so, **give them all.**

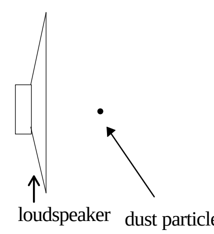


How, if at all, can the demonstrator repeat the original experiment to produce a pulse that takes a longer time to reach the wall. More than one answer may be correct. If so, **give them all. Circle the correct letter or letters.** Explain.

Possible responses for question 1:

a) Move her hand more quickly (but still only up and down once and still by the same amount).
b) Move her hand more slowly (but still only up and down once and still by the same amount).
c) Move her hand a larger distance but up and down in the same amount of time.
d) Move her hand a smaller distance but up and down in the same amount of time.
e) Use a heavier string of the same length, under the same tension
f) Use a lighter string of the same length, under the same tension
g) Use a string of the same density, but decrease the tension.
h) Use a string of the same density, but increase the tension.
i) Put more force into the wave.
j) Put less force into the wave.
k) none of the above.

4. A dust particle is located in front of a silent loudspeaker (see figure). The loudspeaker is turned on and plays a note at a constant (low) pitch. **Which choice or combination of the choices** *a-f* (listed below) can describe the motion of the dust particle after the loudspeaker is turned on? **Circle the correct letter or letters.** Explain.



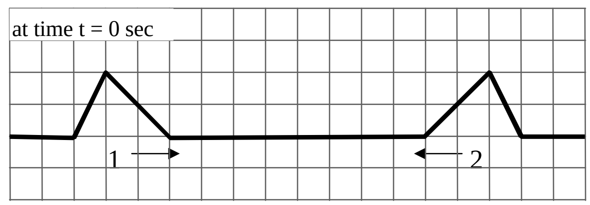
Possible responses for question 2:

g) The dust particle will move up and down.
h) The dust particle will be pushed away from the speaker.
i) The dust particle will move side to side.
j) The dust particle will not move at all.
k) The dust particle will move in a circular path.
l) None of these answers is correct.

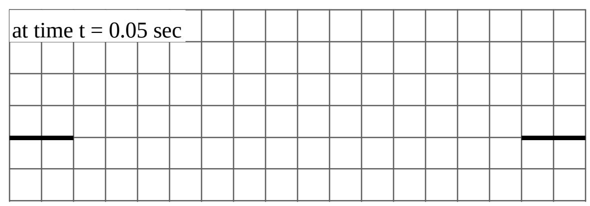
5. Michael and Laura are standing 100 m apart and yell "Yo!" at each other at exactly the same instant. Michael yells louder than Laura, and the pitch (frequency) of his voice is lower. No wind is blowing.

Will Laura hear Michael first, Michael hear Laura first, or will they hear each other at the same time? Explain how you arrived at your answer.

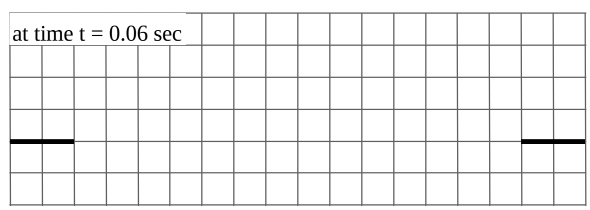
6. Consider two pulses on a spring, as shown in the figure to the right. They are moving toward each other at 100 cm/sec. Each block in the picture represents 1 cm.



In the figure to the right, sketch the shape of the spring after 0.05 sec have elapsed. Explain how you arrived at your answer.



In the figure to the right, sketch the shape of the spring after 0.06 sec have elapsed. Explain how you arrived at your answer.



7. Margaret stands 30 m from a large wall and claps her hands together once. A short moment later, she hears an echo.

How, if at all, would the time it takes for her to hear the echo change if she clapped her hands harder? Explain.

Consider a dust particle floating in the air very close to the wall (within 0.1 mm). Describe the motion, if any, of this dust particle between the moment that Margaret claps and the moment she hears the echo. Explain how you arrived at your answer.