

## **LABORATORY III**

### **WAVES**

Mechanical waves allow us to transfer energy from one position to another without actually moving an object between those two positions. Waves are an important part of every day experience. The gentle ripples in an ocean surface that can become pounding waves on the shore are waves. The music you hear consists of waves that are vibrations of the air. Mechanical waves govern the sounds of musical instruments, and mechanical waves carry the destructive forces of earthquakes. In this lab you will have the opportunity to explore various wave phenomena to help you organize your experiences with mechanical waves.

We will build on our experiences from the last laboratory by using springs as the medium for our waves. Anything that can vibrate, such as wires, water, molecules, and air, can carry waves. In these problems you will investigate what determines the speed of a wave, how to create wave patterns, and the relationship between wavelength, frequency, and speed for a given wave.

#### **OBJECTIVES:**

After successfully completing this laboratory, you should be able to:

- Identify real systems with the mathematical description of waves.
- Identify the properties of the medium that determine the wave velocity.
- Determine the relationship between the wavelength, frequency, and speed of a wave.
- Identify the properties of a system that determine the pattern of standing waves.

#### **PREPARATION:**

Before coming to lab you should be able to:

- Use the properties of sine and cosine.
- Distinguish between frequency and period.
- Distinguish between amplitude and wavelength.
- Distinguish between transverse and longitudinal waves.
- Distinguish between standing and traveling waves.
- Define nodes and antinodes for a standing wave.
- Distinguish between waves and pulses.
- Use a stopwatch to determine the speed of a wave.
- Use a meter stick to determine a wavelength.

## PROBLEM #1: WAVE SPEED

You are part of a team that is designing the power lines that bring electricity to the city from a windmill farm. The specifications require that the power line supports be able to withstand the transverse and longitudinal pulses that might be caused by high winds. Pulses that travel too fast can damage the wire. You have been asked to determine how the tension of the wire affects the pulse speed. You also need to know if this effect is different for transverse and longitudinal waves. To make the waves more observable you decide to use a spring to test your ideas.

### EQUIPMENT

This problem is done using a tightly coiled metal spring that has an unstretched length of about 1.8 meters. **Do not** stretch the spring past its elastic limit: 10 meters. You will also have a meter stick, a stopwatch, and force scales. Hold the stretched spring tightly. Releasing the spring when it is stretched can cause pain and injury to your partner. **Safety goggles must be worn to protect your eyes in the event of an accidental release of one end of a stretched spring. Gloves should be worn to protect your hands.**



**WARNING:** **Never** release one end of a spring that is under tension, because its snapping motion could injure somebody. Always release the tension slowly. **Wear** safety goggles while in the vicinity of the springs. **Wear** a glove on the hand holding the spring.

### PREDICTION

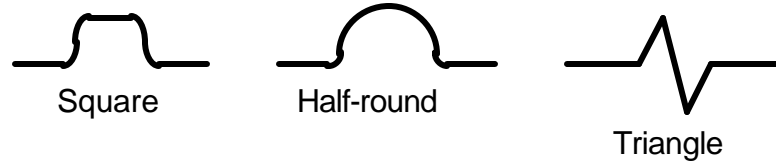
How do you think the speed of a pulse depends on the tension of the spring? Make an educated guess using dimensional analysis (Hint: break the units of tension down into a combination of kilograms, meters, and seconds). Then predict which type of pulse, longitudinal or transverse, is faster on the spring.

Read Serway & Vuille, Chapter 13, Sections 13.6 , 13.7, and 13.8 (or Cutnell & Johnson 16.1, 16.2, 16.3)

### EXPLORATION

Once your group has discussed the predictions and examined the equipment, find a good place to work with the spring. You may need to go out into the halls. Don't forget the **goggles and gloves**. Everyone must wear goggles anytime you are in the vicinity of stretched springs. Two group members will grasp the loops at the ends of the tightly coiled spring using the wooden rods to get a firm grip. Use the force scales to determine how the tension depends on the length of the spring. **Do not** stretch the tightly coiled spring past 10 meters.

Sit on the floor and practice making pulses of different shapes. You need to know if the pulse speed depends on its shape. Try some very different shapes. Be sure everyone in your group gets an opportunity to work with the spring. Learn how to make the following transverse pulses before continuing. Some of these shapes may require several people to make. Record in your journal what you did to make each pulse shape. Which pulse is the easiest one to make?



Observe how your wave pulse evolves with time. Discuss your observations with your partners as you work. Can you make a pulse do a round trip? Note what happens to the pulse when it is reflected from the end of the spring. If you keep the spring tension the same, does the speed depend on the pulse shape?

Practice making longitudinal pulses. Are they easier or more difficult to make than the transverse pulses?

For this part of the exploration, you will examine what the velocity of a wave means. First, you will examine the average velocity of a single coil of the spring. To help you observe the behavior of a single coil, place a piece of tape on a coil in the middle of the spring while the spring is stretched. Send a pulse down the spring and observe the motion of this piece of tape. Try a transverse pulse and a longitudinal pulse. What is the average velocity of the tape? Does the tape wiggle back and forth, or does it end up at one end? What does this tell you about the medium of a wave and the wave itself? Record your observations and measurements in your journal.

Next you will examine how much time it takes for a pulse to travel the length of the spring. How will you know when the pulse has reached the end? Do you want to time the pulse using its front, middle, or back? How do you use this time measurement to get the velocity? How does this velocity compare to the velocity of a single coil of the spring?

What happens to the velocity of the waves if you change the amount that you stretch the spring? What happens to spring tension? Does this imply anything about your prediction? Can you explain? Try some extreme cases.

Find a good way of timing the motion of the pulse. Be sure you have a plan that works for both longitudinal and transverse pulses. Record this plan in your journal. Rotate partners until everyone in the group has had the opportunity to make pulses and work the stopwatch.

<b>MEASUREMENT</b>
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Collect enough data to test your predictions. Be sure to collect data at various tensions for both longitudinal and transverse pulses.

**ANALYSIS**

Do the necessary analysis to confirm your predictions. What are the limitations on the accuracy of your measurements and analysis?

**CONCLUSION**

Can you explain your results? What will you tell your supervisor about the speed of the pulses?

## PROBLEM #2: STANDING WAVE PATTERNS

While talking to a friend on the phone you play with the telephone cord. As you shake the cord, you notice the ends of the cord are stationary while the middle of the cord vibrates back and forth; you have a standing wave. As you change the motion of your hand, a new pattern develops in which the middle of the cord is stationary while the rest of the cord vibrates wildly. You decide to investigate these standing wave patterns

### EQUIPMENT

This problem is done using a tightly coiled metal spring that has an unstretched length of about 1.8 meters. **Do not** stretch the tightly coiled spring past its elastic limit: 10 meters. You will also have a meter stick. Wooden rods will be used to hold the spring by the loops at its ends. **Use gloves.** Hold the stretched spring tightly. Releasing the spring when it is stretched can cause pain and injury to your partner. **Safety goggles must be worn to protect your eyes in the unlikely event of an accidental release of one end of a stretched spring.**



**WARNING:** **Never** release one end of a spring that is under tension, because its snapping motion could injure somebody. Always release the tension slowly. **Wear** safety goggles while in the vicinity of the springs. **Wear** a glove on the hand holding the spring.

### PREDICTION

Find an equation expressing the wavelength of a standing wave in terms of the standing wave pattern, or  $n^{\text{th}}$  harmonic, and the length of the spring.

### WARM-UP

Read Serway & Vuille, Chapter 13, Sections 13.6, 13.7 and 13.8 and Chapter 14, Section 14.8 (or Cutnell & Johnson 17.5)

1. Draw a sketch of the experimental set-up. On this sketch label the directly measurable quantities and the unknown quantities.
2. From your sketch, determine the boundary conditions for the standing wave. Can the ends of the spring move?
3. Draw sketches of the three simplest standing wave patterns that are consistent with your boundary conditions. On your sketch, label the wavelength of each standing wave pattern and the length of the spring.

4. Examine your sketch for the simplest standing wave. The frequency of this wave is defined as the first harmonic. From your sketch, find an equation relating the wavelength of the standing wave to the length of the spring.
5. Examine your sketches for the other standing waves. The frequencies of these waves are called the 2<sup>nd</sup> and 3<sup>rd</sup> harmonics. Using your sketches, find equations relating the wavelength of the standing wave pattern to the length of the spring for each harmonic.
6. Do you see a pattern in your three equations? For an arbitrary standing wave pattern, or  $n^{\text{th}}$  harmonic, find an equation expressing the wavelength of the standing wave as a function of  $n$  and the length of the spring.

### EXPLORATION

To create standing waves on the spring, first get a feeling for how traveling waves can become standing waves. Three wave properties are important: (1) how waves travel, (2) how they are reflected at boundaries, (3) how two waves combine. You've already spent some time exploring the first two properties of pulses in the previous problem. You should use this experience to determine the length of the stretched spring.

To see how two traveling pulses combine, send a half-round pulse down the spring from each end. Carefully observe what happens when the two pulses meet? Are the observations easier with a slow speed or a fast speed? Draw this interaction in a series of sketches. Can you make this interaction occur so that a coil in the middle of the spring does not move? Try sending a half-round pulse down the spring and as soon as the pulse hits your partner's hand, send another one. What happened when the two pulses met? Record your results and explanations in your lab journal.

Now use your experience with traveling waves to make standing waves. Start by sending half-round pulses down the spring so that the middle of the spring does not move. Start sending more pulses down the spring in increasing rapid succession. Maintain this process until a standing wave develops on the spring.

Practice making standing waves on the spring. What is the simplest pattern you can develop? What is the most complex pattern you can develop?

After each of your partners has learned how to set up standing waves, develop a measurement plan for determining the wavelength of each standing wave pattern.

### MEASUREMENT

Execute your measurement plan for determining the wavelength of the standing wave for as many different patterns as you can produce on the spring. Make sure to record which harmonic, or pattern, you are examining.

**ANALYSIS**

For each measurement, how does the wavelength depend on the length of the spring? Use your results to determine a general relationship between the wavelength of a standing wave and the length of a spring for an arbitrary pattern.

**CONCLUSION**

How does the wavelength of a standing wave depend on the standing wave pattern and the length of the spring? Is this what you predicted?

## **PROBLEM #3: STANDING WAVE VELOCITY**

You have been working for a team that is designing the power lines that bring electricity to the city from a windmill farm. The specifications require that the power line supports be able to withstand the transverse and longitudinal pulses that might be caused by high winds. Pulses that travel too fast can damage the wire. One concern you have is that standing waves might form in the power lines. Since standing waves can be created by the addition of individual pulses, you are worried that the velocities of these pulses might also add, which could damage the power line. However, your colleague tells you that the velocities of the individual pulses don't add and the velocity of the standing wave is the same as the velocity of the individual pulses. To see who is right, you decide to use a spring to test your ideas.

### **EQUIPMENT**

This problem is done using a tightly coiled metal spring that has an unstretched length of about 1.8 meters. **Do not** stretch the tightly coiled spring past its elastic limit: 10 meters. You will also have a meter stick, a stopwatch, and a force scale. Wooden rods will be used to hold the spring by the loops at its ends. **Use gloves.** Hold the stretched spring tightly. Releasing the spring when it is stretched can cause pain and injury to your partner. **Safety goggles must be worn to protect your eyes in the unlikely event of an accidental release of one end of a stretched spring.**



**WARNING:** **Never** release one end of a spring that is under tension, because its snapping motion could injure somebody. Always release the tension slowly. **Wear** safety goggles while in the vicinity of the springs. **Wear** a glove on the hand holding the spring.

### **PREDICTION**

Draw a graph of how the wavelength of a standing wave on the tightly coiled spring depends on the period of oscillation of your hand. What is the slope of this graph?

Using your experience in problem #1, write the equation expressing the velocity of a transverse pulse as a function of the tension in a spring.

Read Serway & Vuille, Chapter 13, Sections 13.6, 13.7 and 13.8 and Chapter 14, Sections 14.8 (or Cutnell & Johnson 16.2, 16.3, and 17.5)



**EXPLORATION**

The exploration for this problem is very similar to problem #2. For help in creating standing waves on the spring, refer to the Exploration section in problem #2.

Measure the tension in the spring. Make sure to keep this tension constant as you are changing the standing wave patterns.

Practice making standing waves on the spring. What is the most and the fewest nodes you can develop on the spring?

After each of your partners has learned how to set up standing waves, develop a measurement plan using the stopwatch to measure the period of oscillation of the standing wave.

Develop a measurement plan for determining the wavelength of each standing wave pattern.

**MEASUREMENT**

Execute your measurement plan for determining the period of oscillation and the wavelength of the standing wave for each pattern. Make sure to keep the tension in the spring the same for each pattern.

Measure all other quantities necessary to determine the velocity of a transverse pulse.

**ANALYSIS**

From your measurements, make a graph of how the wavelength of a standing wave on the spring depends on the period of oscillation of your hand. What does the slope of this graph represent? Compare it to your calculated value of the velocity of a transverse pulse.

**CONCLUSION**

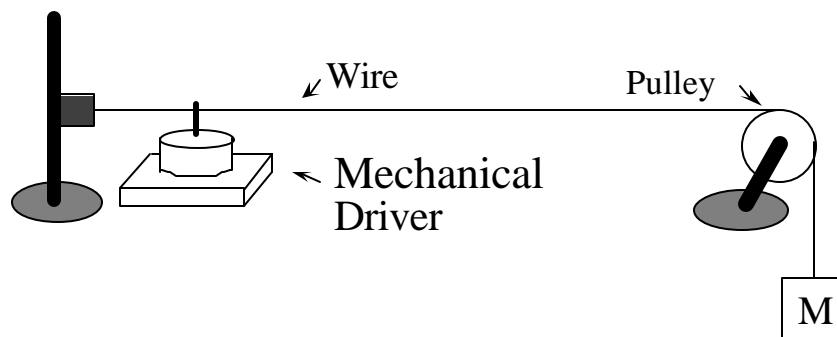
Is the velocity of a standing wave the same as the velocity of a transverse pulse on a spring with a given tension? Since a standing wave doesn't exhibit longitudinal motion, what do we mean when we say "velocity of a standing wave".

## PROBLEM #4: STANDING WAVES

You are part of a quality control team for a factory that manufactures guitar strings. To make sure the strings are all made to the same high standard, you have decided to make a test facility that measures the harmonic frequencies (the frequencies that create standing waves) of the guitar string as a function of the string's tension. You decide that the best way to do this is to set up a pattern of standing waves at known tensions.

### EQUIPMENT

You will use a mechanical driver and a function generator to generate the standing waves. You will also have a length of wire to serve as the wave medium. You will use a pulley, a mass hanger and some calibrated masses to apply a known tension to the end of the wire. The wire is fastened to the stand at one end of the table and hangs over the pulley at the opposite end. The mechanical driver should be underneath the wire near one end of the table. The function generator allows you to shake the wire at a wide range of frequencies.



### PREDICTION

Calculate the wave velocity as a function of the frequency of the standing wave and other quantities you can measure in the lab using standing waves. How will changing the tension affect wave speed? How will changing tension affect the frequency of a specific standing wave?

### WARM-UP

Read Serway & Vuille, Chapter 13, Sections 13.6, 13.7 and 13.8 and Chapter 14, Sections 14.8 (or Cutnell & Johnson 16.2, 16.3, and 17.5)

1. Draw a sketch of the experimental set-up. On this sketch label the quantities you can measure and the unknown quantities.

2. Write down the boundary conditions for the standing wave.
3. Sketch a few of the standing wave patterns possible for your boundary conditions and determine the wavelengths of each wave pattern.
4. Use the relationship between a wave's speed, its wavelength, and its frequency. What is the relationship between the wave's frequency and the frequency of the mechanical driver?
5. How will changing the tension affect the wave's speed? How will this change in the wave's speed affect the frequency for various standing wave patterns?

**EXPLORATION**

Begin with the function generator with the power off. Connect it to the mechanical vibrator using the two banana-plug cables, being careful to use the black GROUND terminal and the red LOW terminal on the function generator. Make sure the driver's lock mechanism has been released. Turn the generator's amplitude all the way down. Now turn the power on, and let the function generator warm up while you set up the rest of the equipment.

Choose a length of wire, or check with your TA to see if your group will be assigned a particular wire. Determine the most effective way of setting up the equipment for this problem.

Decide on a comfortable range of masses that you will use. You don't want to stretch or damage the wire, but you will want a mass that will give you the sufficient tension to produce standing waves for several frequencies. If the wire is not pulled straight, or if the mass jumps around a lot when the wire is vibrating, you will need more mass to get usefully data.

Determine the range of amplitudes for the driver. Does the amplitude of the mechanical driver affect the wave speed or the standing wave pattern?

Now plan a way to drive the wire using the mechanical driver. Remember that you want the driver to interfere as little as possible with the motion of the wire. Will it be useful to alter its position for different standing wave patterns? Decide on a strategy to find the frequency values that produce standing waves.

How many nodes can you produce on the vibrating wire? How does changing the tension in the wire at a given frequency affect the number of nodes? Pull gently on the wire to find out. (Here you are varying the tension with your fingers.)

How many standing wave measurements will you take to confirm the validity of your prediction? What quantities will you change that affect your measurements? What quantities will you keep the same?

Record your answers to these questions, the explanations behind your answers, and your measurement plan in your journal.

**MEASUREMENT**

Determine the wire tension and the length of the wire. Arrange the equipment into the configuration you think will minimize the disturbance caused by the driver. Carefully tune to the lowest frequency that produces a standing wave. Raise the frequency and try other standing wave patterns.

Follow your measurement plan to acquire enough data to convincingly determine the wave speed as a function of frequency.

**ANALYSIS**

Using your measurements, compute the wave speed using standing waves on the wire for several different frequencies at a given tension. Do all the frequencies give the same wave speed? What is the uncertainty in your analysis and measurements? Repeat the process for enough other tensions to see the functional relationship between the frequency of specific standing waves and tension.

**CONCLUSION**

Were you able to determine the wave speed using a standing wave? Did wave speed depend on the number of nodes in your standing wave pattern? Did the frequencies of the standing waves depend on the tension in the wire? Did wave speed depend on the amplitude of the standing waves?

What happened to the sounds as you changed the frequency of the driver? What can you deduce about the behavior of guitar strings and the sounds they make?



## CHECK YOUR UNDERSTANDING

1. A standing wave on a string can be constructed from two traveling waves that move in opposite directions. Can a traveling wave be constructed from the sum of two standing waves?
2. When transverse positive and negative pulses (that have the same symmetric shape and size but travel in opposite directions) meet, is it necessary that there be a moment when the string on which they move is flat? If so, how do the pulse "know" to continue moving on the string?
3. Explain what would happen to the lowest frequency standing wave if the tension in the wire were increased.



TA Name: \_\_\_\_\_

## PHYSICS 1102 LABORATORY REPORT

### Laboratory III

Name and ID#: \_\_\_\_\_

Date performed: \_\_\_\_\_ Day/Time section meets: \_\_\_\_\_

Lab Partners' Names: \_\_\_\_\_

\_\_\_\_\_

Problem # and Title: \_\_\_\_\_

Lab Instructor's Initials: \_\_\_\_\_

Grading Checklist	Points
<b>LABORATORY JOURNAL:</b>	
<b>PREDICTIONS</b> (individual predictions and warm-up completed in journal before each lab session)	
<b>LAB PROCEDURE</b> (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
<b>PROBLEM REPORT:*</b>	
<b>ORGANIZATION</b> (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
<b>DATA AND DATA TABLES</b> (clear and readable; units and assigned uncertainties clearly stated)	
<b>RESULTS</b> (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
<b>CONCLUSIONS</b> (comparison to prediction & theory discussed with physics stated correctly; possible sources of uncertainties identified; attention called to experimental problems)	
<b>TOTAL</b> (incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
<b>BONUS POINTS FOR TEAMWORK</b> (as specified by course policy)	

\* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.

