Introduction:

When a string of length $L$ clamped at both ends is driven sinusoidally, standing waves can be generated when there are an integral number of half-wavelengths on the string. That is, when $L = n\lambda/2$, where $n = 1, 2, \ldots$

Since $\lambda = v/f$ and

$$v = \sqrt{\frac{F}{\mu}},$$

then

$$\lambda = \frac{L}{f} \sqrt{\frac{F}{\mu}}.$$

$F$ is the tension in the string and $\mu$ is the mass per unit length of the string. In this experiment, the string will be driven at 60 Hz by a mechanical vibrator at one end of the string, and the tension will be determined by the weight of a mass hanging from the other end of the string by a pulley, as shown below. In this example, there are two “loops” in the standing wave and three nodes (the points of destructive interference).

Putting the above formulas together, we get

$$\lambda = \frac{1}{f} \sqrt{\frac{mg}{\mu}} = \frac{2L}{n}$$

$n$ is the number of loops

Equipment: Oscillator with string, aluminum track, plastic cup with string, sand, masses, mass hanger, pair of banana cables, plastic cup

Preliminary Questions

1. Suppose you have established a standing wave on your string. If you pull down on the string to increase the tension $F$ until another standing wave is created, will the wavelength of the new standing wave be greater or less than the first?
2. The following figure shows a standing wave on a string; if the tension is quadrupled draw the new standing wave (constant frequency)

![Standing Wave Diagram]

3. Refer to question 2. What if the tension is tripled, will you get a standing wave? Explain.

4. If a standing wave with 5 loops is created on a string of length 2.0 m, what is the wavelength of the standing wave?

**Procedure**

Find the mass per unit length of your string (your instructor might give you this number):

\[ \mu = \phantom{000} \]

In the following PART 1 and PART 2 your goal is to create standing waves of different wavelengths; notice however that you must consider only standing waves for which there is a node at the oscillator (where the string is attached to the oscillator - as shown in the first figure of front page). In other words you DO NOT want to consider the cases where the amplitude is max at the oscillator, for example as show below (if you observe one of these standing waves, change the frequency or the mass):

![Standing Wave Diagram with Node]

**PART 1** – (Constant mass, varying frequency)

Connect the string oscillator to the ScienceWorkshop interface: use the banana cables, one for the each (±5V/300mA) outputs located at the right end of the interface. Open Data Studio, Create Experiment, on the Experiment Setup window look at the bottom of the Sensor tab and double click the word ‘Output’ next to the sine icon. The Signal Generator window and the sine wave icon (under the output) will appear on your screen. Now you can produce oscillations on your string of different amplitudes and frequencies. Place on the hanger a mass of about 100 grams. We want to explore which frequencies will produce standing waves (of different wavelengths). Start with an initial frequency of 20 Hz and Amplitude of 2.0 Volts, press ‘Start’ on Datastudio and please do not let the oscillation last too long (to avoid too much noise in the classroom)

**Questions**

1. Do you see a standing wave?
2. Increase the frequency until you see a standing wave, how many nodes are present?

3. What is its wavelength?

4. Calculate the expected frequency \( f_C \) from equation (1) and compare it with the frequency you input in the Signal Generator \( f_{SG} \)

\[
\begin{align*}
f_C & \quad f_{SG} \\
\text{Percentage error: } &= \left( \frac{|f_C - f_{SG}|}{f_C} \right) \times 100
\end{align*}
\]

5. Input the expected frequency in the Signal Generator, what difference do you observe now?

6. Try to obtain a standing wave with one loop, first calculate the frequency which will give only one loop

\( f_{\text{One Loop}} \)

7. Use the above frequency in the Signal Generator and check your prediction:

**PART 2 – (Varying mass, constant frequency)**

Connect the string oscillator to the AC power supply and gradually add sand to the cup hanging from the end of the string in order to obtain a standing wave. Measure its wavelength \( \lambda \), the mass of the cup + sand \( m \) and observe the corresponding number of loops \( n \). Then add more sand, until you see the next standing waves and repeat the measurements. With care, you can obtain from 2 to 5 half-wavelengths on the string. Note that the distance from node to node is one-half wavelength, not one wavelength.

Now use your data to verify Eq. (1). A good way to do this is to plot \( \lambda^2 \) versus \( m \) and show that the plot is a straight line. From the slope you can calculate \( f_o \), the frequency of oscillation. NOTE: the slope is not equal to \( f_o \).

Write below the equation which relates the slope and \( f_o \)

\[
\text{slope} = \frac{n \cdot \lambda^2}{m}
\]

<table>
<thead>
<tr>
<th>( n )</th>
<th>Mass ( m )</th>
<th>( \lambda )</th>
<th>( \lambda^2 )</th>
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<tr>
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**Questions**

1. Does your data confirm Eq. (1)? Explain.

2. Using \( g = 9.81 \text{ m/s}^2 \), calculate the value of \( f_o \) from the slope of the graph: \( f_o = \) _______

3. How does your value for the frequency \( f_o \) compare to the expected value \( f_{60} = 60 \text{ Hz} \)?

\[
\text{Percentage error: } = \left( \frac{|f_{60} - f_o|}{f_{60}} \right) \times 100 = \text{_______}
\]

4. What are the sources of error in your experiment?