PHYSICS 221

EXPERIMENT 2: Waves

INTRODUCTION :

As you already know, various types of wave phenomena are an integral part of our physical world. Thus an understanding of wave behavior is essential in understanding basic physical concepts. In this lab, we will study transverse waves traveling on a string and ultrasonic waves interfering with one another.

THE STUDY OF STANDING WAVES IN A WIRE

When a string is stretched between two fixed points, its fundamental mode of vibration will consist of a single segment with nodes on each end. If the string is driven at this fundamental frequency, a standing wave is formed. Standing waves also occur if the string is driven at any integer multiple of the fundamental frequency. These higher frequencies are called the harmonics. For a given harmonic, the wavelength is

$$\lambda = 2L/n \tag{1}$$

where L is the length of the stretched string and n = 1,2,3,… is the number of segments in the string (see Figure 1). Notice that n also corresponds to the number of antinodes in the standing wave.

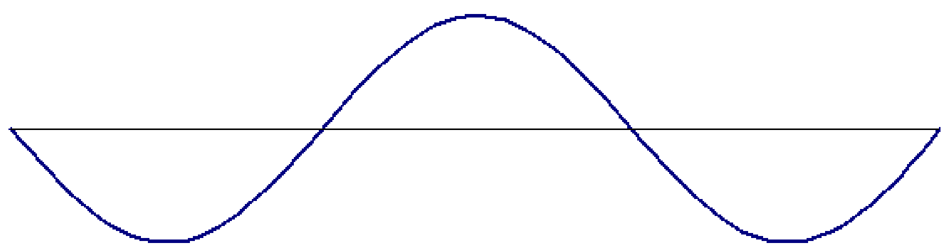

Figure 1 : Standing wave on a string for n = 3.

The linear mass density μ of the string can be directly measured by weighing a known length of the string: μ = mass/length. The velocity of a wave travelling on a string under tension T can be expressed as

$$v = \sqrt{\frac{T}{\mu}}\,. \tag{2}$$

For any wave, the velocity can be expressed as $v = f\lambda$ where f is the frequency of the wave. Using Equation 1, we can also express the velocity of the wave as

$$v = \frac{2Lf}{n}\,. \tag{3}$$

PROCEDURE :

To set the string (in this case a thin conducting wire) into motion, we will pass a current through it. Part of this string passes through a region with a magnetic field. This produces a force on the string. If we use an alternating current, the direction of the force will continually reverse direction, thereby allowing us to apply a driving frequency to the wire.

1. The experiment should be set up as in Figure 2. An ac current coming from a frequency generator is sent through a transistor amplifier to increase its magnitude. The ac current will then be traveling through a taut wire that runs through a magnet. It is the magnetic field coming from the magnet that exerts a force on the current-carrying wire, setting it into motion.

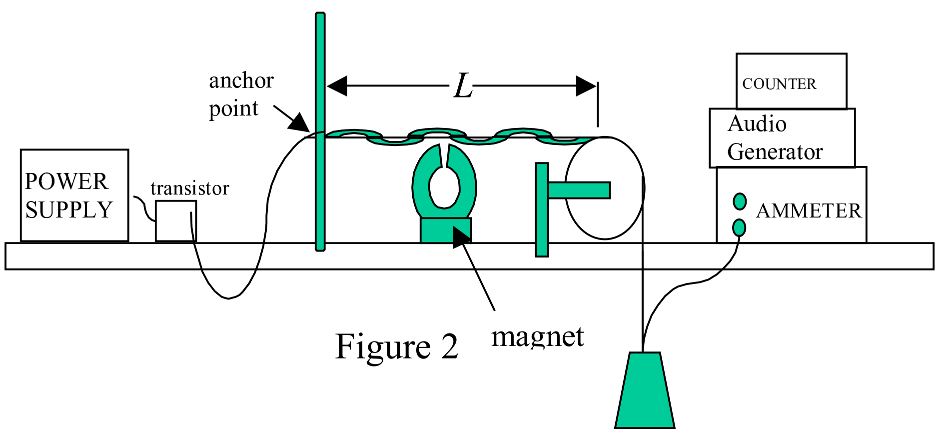

Figure 2

2. Find the mass density μ of the wire using a sample wire identical to the type used in the experiment.
3. Next, attach a mass holder to the loop end of the wire in the set-up and add enough mass so that the wire is taut (this may already be done for you).

4. Record the exact value of the mass holder plus the additional masses, and calculate the tension in the wire.
5. Measure the length of the wire between the point where it is anchored and the top of the pulley where the wire rests. This distance is labeled as L in Figure 2.
6. With the values you have obtained, calculate the expected frequencies for $n = 3$. This will give you a rough value to set your current frequency to find the third harmonics. [You are enot asked to look for $n = 1$ and 2 harmonics because, depending on the tension of the string, these harmonics may be rather difficult to find.]
7. At the frequency you calculated, you should see three segments of a standing wave on our string. Fine tune the frequency so that the amplitude of the wave is maximum. You may also need to adjust the position of the magnet so that it is located at an antinode (preferable close or at the center of the string). Make sure the wire is not touching the magnet. You may need to go back and forth between adjusting the frequency and the magnet position until you have the maximum amplitude.
8. When you obtain the maximum amplitude of vibration, record the exact frequency for $n = 3$ harmonic.
9. Do the same for $n = 4$, 5, 6, etc. Try to find as many as possible. You may even want to go back and see if your setup can give the $n = 1$ and 2 harmonics. For all n, it is considerably easier if you first calculate what the theoretical frequency is and use that as a guide to set the frequency of the signal generator. Record in your report only the *experimental values*, not the calculated values!

ANALYSIS :

1. Plot a graph of the frequency f versus n.
2. In your theory section, show that the slope best-fit straight line of this graph is equal to $v/2L$.
3. From your best-fit line, find $v/2L$, and compare the velocity of the wave obtained with that found from Equation 2. Discuss reasons for possible error.

THE STUDY OF SOUND WAVE INTERFERENCE

This experiment deals with the interference of sound waves in two-dimensions. This experiment was originally done using light in 1801 by Thomas Young in the double slit experiment. Here, the experiment will be recreated using sound.

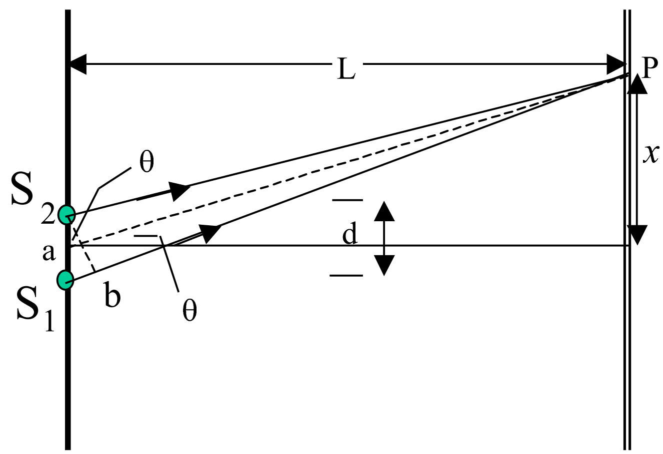

Figure 3

Two identical sound sources are placed next to one another. A receiver P, is placed a horizontal distance *L* from two, identical sound sources, S_1 and S_2, as shown in Figure 2. The distance between S_1 and S_2 is denoted by *d*, and *a* is the midpoint between S_1 and S_2. Point *b* in the figure is a point such that the distance from S_2 to P is the same as the distance from *b* to P. The remaining distance between S_1 and *b* is the extra distance that the sound waves from S_1 need to travel to P, the receiver. It is this extra travelling distance that causes the interference between the two waves. If this distance from S_1 to *b*, labeled S_1b, (not the product of S_1 and *b*) contains an integral number of wavelengths, i.e.

$$S_1b = m\lambda \qquad\qquad m = 1,2,3,\ldots$$

then the two waves will be in phase at the receiver and there will be a constructive interference. Thus, a loudest sound results at the receiver. If the difference is a half-multiple of an integral number of wavelengths, then a minimum sound amplitude results.

From Figure 3, one can show that

$$m\lambda = d\sin\theta \qquad \text{for a maxima} \tag{4}$$

$$(m + \tfrac{1}{2})\lambda = d\sin\theta \qquad \text{for a minima.} \tag{5}$$

where m is an integer.

From Figure 3, we can see that

$$\sin\theta = \frac{x}{\sqrt{x^2 + L^2}}\,. \tag{6}$$

This means that, for example, the angular position of the third maxima can be found from

$$\sin\theta_{m=3} = \frac{x_3}{\sqrt{x_3^2 + L^2}}$$

where x_3 is the position of the third order maximum; $m = 3$.

Thus, from the positions and the values of m, the wavelength may be determined. Using these calculated wavelength values and the equation $v = f\lambda$ the velocity of sound through the medium may be found.

PROCEDURE :

Young's Double Slit experiment will be performed using sound waves, instead of light.

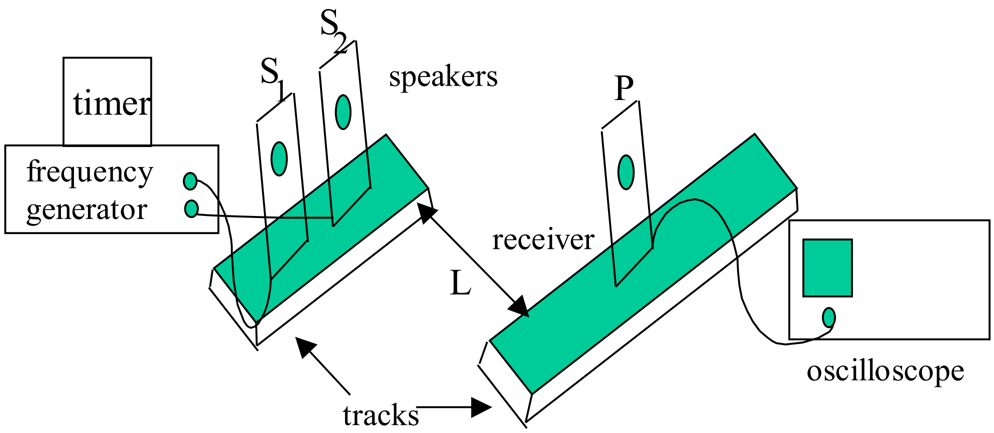

Figure 4

The experimental set-up for this part is shown in Figure 4. S_1 and S_2 are the two speakers creating the sound waves. P denotes a single microphone connected to an oscilloscope in order to detect incoming waves. By sliding the microphone along the track, the intensity of the receiving signal at different locations will be measured. Before beginning this experiment, be sure to measure the room temperature so the theoretical velocity of sound in air may be determined. This can be accomplished by using the equation

$$v = 20.05\sqrt{T} \ .$$

where T is the temperature in Kelvin.

1. Two speakers are connected to the same frequency generator. This ensures that the two waves coming from the speakers are both of the same frequency and the same phase. Record the frequency of the sound waves used.
2. Set the speakers apart from each other a small distance d.

3. Align the microphone's track so that it is parallel to the track holding the speakers. The perpendicular distance between the tracks is labeled L in Figure 4. Measure and record L.
4. Set the microphone at the center of its track, and mark and record this position. To obtain a better understanding of what is being measured, slide the microphone up and down the track (without recording any data), and watch as the receiving signal on the oscilloscope gets weaker and stronger.
5. Return the microphone back to its center position. Now, slowly slide the microphone to one side of the center position (either to the left or right) while continuously monitoring the amplitude of the signal. When the signal reaches a first maximum amplitude, label this as $m = 1$ and record this distance x from the center position.
6. Slide this further down the track to obtain subsequent maxima (m = 2,3, …) and record all their positions with respect to the center position.
7. Repeat this on the other side of the center position, obtaining the corresponding maxima positions for m = 1,2,3,…, etc.
8. Create a table consisting of a column representing n, a column consisting of x_L (for the maxima positions on the left of the center), a column consisting of x_R (for the maxima positions on the right of center), and the average x position.
9. Repeat the experiment for one other value of d.

ANALYSIS :

1. Using Equation 6, find θ for each m. Add this to your data table.
2. Plot $\sin\theta$ versus m.
3. Prove in the theory section of your report the relationship between the slope of the straight-line fit and λ. Using the best-fit line, find λ from your graph and compare this with the given value (this may be found by finding the velocity of sound in air and dividing it by the sound's frequency).