LAB 1: MECHANICAL STANDING WAVE: MELDE'S EXPERIMENT

During this laboratory session, students will

✔1 encounter mechanical transverse wave in a string that will stand between two points,

✔2 visualize nodes and antinodes that define wavelengths ("length of a wave"),

✔3 measure the speed of propagation of a mechanical wave and relate it to the tension in the string,

✔4 once more choose their independent and dependent variables,

✔5 get the feeling of the birth of quantum mechanics.

Student Learning Outcome: Successful students

✔1 understand the difference between a standing wave and a traveling wave,

✔2 master the two cases of standing waves: open–open (closed–closed) ends and closed–open ends,

✔3 know how frequency, wavelength, and speed are related to each other,

✔4 be ready to experimentally study beat, interference, and diffraction.

INTRODUCTION

Standing waves may be set up in a string when two equal and opposite waves are superimposed. This is accomplished in the laboratory by means of a light string, one end of which is fastened to the end of a blade that is periodically attracted by an electromagnet. The other end of the string is passed over a pulley and tied to a weight hanger (see the figure).

Mount the apparatus according to the model shown in this photo. Beware that the electromagnet is on as soon as you plug the charger into the 110 V. Unplug it when you do not measure so that it will not overheat.

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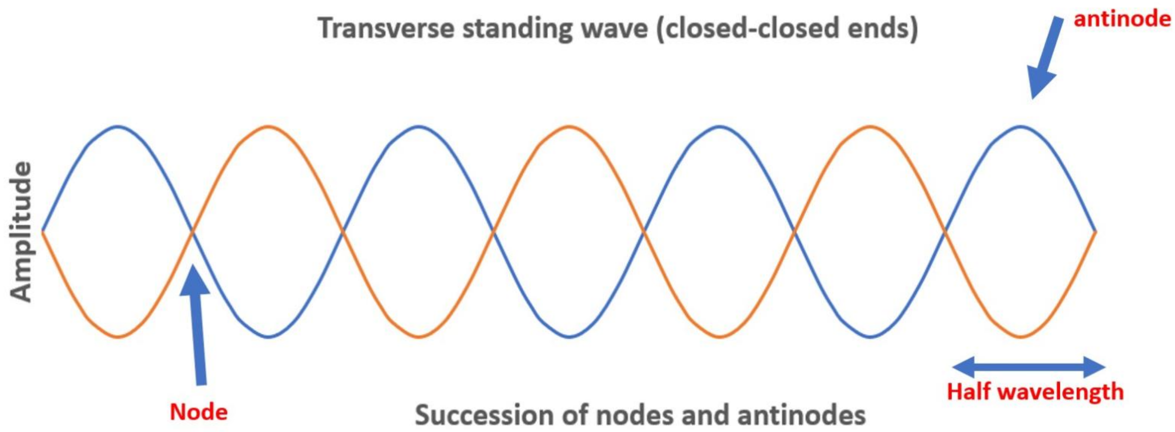
The standing wave is characterized by the existence of locations on the string that experience no displacement. These locations are called nodes. The regions of the waveform where maximum displacement occurs are called antinodes. A full wave spans from a node to the second next node; a node-to-node distance is as long as a half of a wavelength or λ/2.



When the wave stands, the shape of the string will switch back and forth between the shape in blue and the shape in orange. The back-and-forth motion, also called oscillation, happens really fast. In our case, the frequency would be about 120 Hz. In another word, the string will be in that shape in blue 120 times per second.

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By properly changing the tension on the string, you can change the number of nodes in the standing wave, that is, the wavelength changes. Also, the wavelength is affected by the frequency of the electromagnet responsible of the fast back-and-forth motion of the blade. Finally, you could suspect that the number of waves could depend on the properties of the string such as its linear density (mass per unit length).

PROCEDURES

Physical Setup

On one side of the table, stabilize the electromagnet and its blade by using the bolt and the nut provided to you. Mount the pulley at the other side of the table. Use a table mount to attach a pulley if necessary. Tie the hanging mass to the end of the string and place it over the pulley so that it hangs over the table.

Standing Waves: Part 1

1. Find a mass between 500 and 1,000 g in order to get a nice standing wave—you can increment by 10 from 500 g as a rough tuning until the wave is about to stand, then increment by lighter mass to fine tune to a standing wave. *Count the number of nodes* because you will use that number to define each standing wave (Introduction, second paragraph). Indeed, a range of masses may yield to the same number of nodes, but only one mass of that range makes the wave stand perfectly. It is worthy to notice that a standing wave is defined by its wavelength. The standing wave with the longest wavelength is called first harmonic, the second longest is the second harmonic, and so on. **Thus, counting the number of nodes is one easy way to identify the standing harmonic.**

2. You should measure the wavelength from node to node. Best precision is obtained when the distance measured is as large as possible (the same principle in why we always find the slope on graphs from the extreme ends of the line). However, the string is not quite at a node where it is attached to the blade and, on the other side, it is extra hard to find the node at the pulley.

   Therefore, if possible, <u>**measure the distance from the first node after the blade to the last node before the pulley.**</u> That distance divided by the number of antinodes, <u>**over that same distance**</u>, will be one-half wavelength.

3. Find at least four other <u>**tensions**</u> that give nice different harmonics (so at least a total of five harmonics). Each tension should have a different number of wavelengths on the string (**count the number of nodes—they should be different for each tension**). Determine the wavelengths for the various tensions using the technique discussed in the previous step.

4. Plot the wavelength λ (in meter) as a function of the tension T (in Newton).

5. Your plot#4 is not linear and should suggest that λ is power function of the tension. Let $\lambda = CT^n$, where C is a proportionality constant which may depend on the frequency, f, and the linear density of the string—power trendline in Excel. Another way to find the power “n” is to take the logarithm

of both sides of the equation to get

$$\log[\lambda] = \log[C] + n \log[T] \qquad (1)$$

You may plot λ versus T on a log–log graph and then find the experimental value of n.

Choose either log–log plot or the power plot and state the measured value of "n."

Standing Waves: Part 2

Only the pole of the electromagnet that will attract the blade is visible, the other pole being hidden at the bottom of the apparatus. That visible pole will switch from north to south (or vice versa) 60 times per second because the AC wall outlet frequency is 60 Hz. As the pole attracts the blade whether it is being north or south, the standing wave frequency should be double of the AC wall outlet frequency. Notice that we do not have the mean to change the outlet frequency and, if the length of the string is kept constant, the hanging mass would be the only changeable parameter. Thus, the measurements were done in part #1: changing the mass would change the wavelength.

But there is more that could be extracted from the data. For this part #2, we will assume that the standing wave frequency is exactly 2 × 60 Hz = 120 Hz. Then, you will measure the lineic mass of the string and compare your measurement to the known value of 0.0003 kg/m. Using your answer to "Preliminary work #3," find the relationship between the tension and the square of the wavelength. The lineic mass should be part of the slope of the graph of T versus λ.

Also, you are asked to use the LINEST fit function for the first time. The LINEST fit is a more powerful tool because it gives more information than the trendline. Watch **Using LINEST in Excel (https://www.youtube.com/watch?v=6wbcPbYbq6M)** that gives a step-by-step instruction on how to do the LINEST in Excel (or another video that you can find on the internet).

Standing Waves: Part 3

Assuming that the lineic mass of the string is 0.0003 kg/m, measure the frequency of the AC outlet. Compare to the known value of 60 Hz—be mindful of the factor 2 (2×60 Hz = 120 Hz). **You need also another graph for this and required to use the LINEST fit in Excel.**

QUESTIONS

1. At constant tension, to what power of frequency is the wavelength dependent?
2. Explain why it is possible to find "n" in eq. (1) without knowing how frequency and density affect the wavelength.
3. List out the differences between a standing wave on a string and a standing sound wave.

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