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# Laboratory Report

# Measuring the Speed of a Wave


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## ABSTRACT

This experiment aims to determine the **speed of a wave** using **two** different **approaches**. The **first** method involves analyzing standing waves formed on a **string subjected to different frequencies** and **node** formations. The **second** method calculates wave speed based on the **physical properties of the string**, specifically its **tension** and **mass per unit length**. A sine wave generator (Figure 1) was used to create standing waves, and data were collected by measuring the number of nodes and corresponding frequencies. The results obtained from both methods were compared, and potential sources of error were analyzed.


FIGURE 1. *A sine wave generator that varies the frequency to establish standing waves.*

## INTRODUCTION:

Waves propagate through a medium with a **velocity dependent** on the **properties of that medium**. In the case of a vibrating string, the velocity of a **transverse wave** can be found using **two** distinct **approaches**. The **first method** is based on the **standing wave equation**, where the speed of a wave is **proportional** to its **frequency and wavelength**. The **second method** relies on physical properties such as **tension** and **mass per unit length** of the string.

A **standing wave** is created when two waves traveling in opposite directions interfere constructively and destructively, producing **nodes** (*points of no motion*) and **antinodes** (*points of maximum motion*) (Figure 2). The **number of nodes** determines the **harmonic mode** of the wave, influencing the calculated velocity.

This experiment investigates the accuracy of both methods by measuring the wave speed and comparing results.

# STANDING WAVE

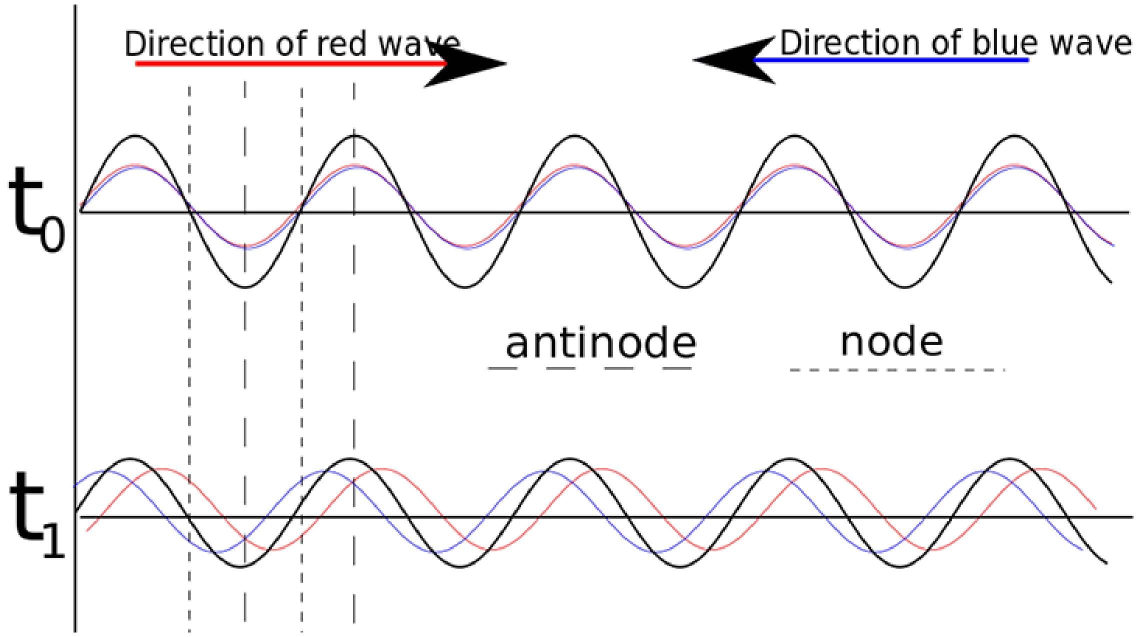



FIGURE 2. *This diagram illustrates the formation of a **standing wave** due to the interference of **two** traveling waves moving in **opposite directions**. The **red** and **blue** waves represent the incoming and reflected waves, respectively, while the **black** wave is the **resulting** standing **wave**. The standing wave consists of **nodes** (points of no displacement) and **antinodes** (points of maximum displacement), which remain **fixed** in position over time.*

## THEORETICAL BACKGROUND

A **standing wave** in a **string under tension** follows the **fundamental wave equations** derived from the wave equation and **Newton's second law**.

### WAVE SPEED CALCULATION USING GENERAL WAVE EQUATION:

When a string is fixed at both ends and subjected to a vibrating source, it forms standing waves. These waves are characterized by **nodes** (points of no displacement) and **antinodes** (points of maximum displacement). The fundamental frequency and harmonics follow the relationship:

$$f_n = \left(\frac{n}{2L}\right) v$$

where:

- $f_n$ is the frequency of the $n$th harmonic (Hz),
- $L$ is the length of the string (m),
- $v$ is the wave speed (m/s),
- $n$ is the number of nodes.

The **wavelength $\lambda_n$** for the th harmonic is given by:

$$\lambda_n = \frac{2L}{n}$$

Substituting into the **general wave equation:**

$$v = f_n \lambda_n$$

The **speed** can be expressed as:

$$v = \frac{2L f_n}{n}$$

## WAVE SPEED CALCULATION USING TENSION AND LINE DENSITY:

The second method of determining wave speed relies on **Newton's laws** and the **fundamental equation of motion for waves** on a string:

$$v = \sqrt{\frac{F_T}{\mu}}$$

where:

- $F_T$ is the tension force in the string (N),
- $\mu$ is the linear mass density of the string (kg/m).

The tension in the string is caused by the **gravitational force** of the **hanging mass**(Figure 3):

$$F_T = mg$$

Where:

- $m$ is the mass hanging from the string (kg),
- $g$ is the acceleration due to gravity (9.8 m/s$^2$).

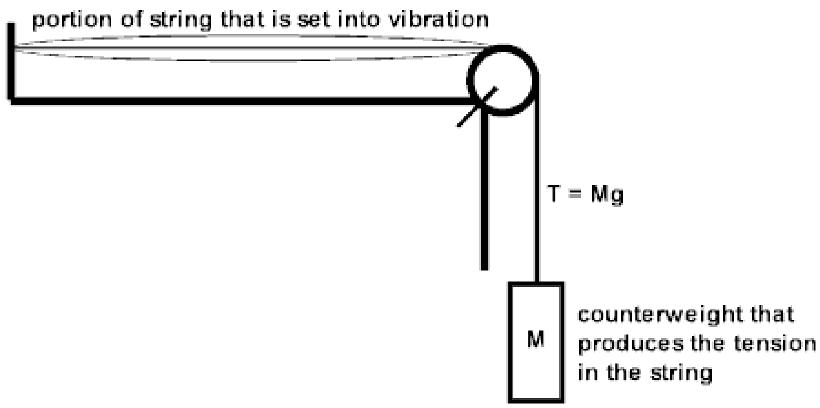



FIGURE 3. *This diagram illustrates the experimental setup where a vibrating string is tensioned by a hanging counterweight.*

The **linear mass density $\mu$** is found by:

$$\mu = \frac{m_{string}}{l_{string}}$$

Where:

- $m_{string}$ is the total mass of the string (kg),
- $l_{string}$ is string's length (m).

# PROCEDURE

## MATERIALS:

- Sine Wave Generator (Figure 1)
- Lightweight string with a consistent diameter (measured mass and length)
- Pulley system with hanging mass (Figure 6)
- Ruler for measuring string length
- Digital scale for measuring string mass

## SETUP:

To ensure accurate and reproducible results, the experimental setup must be carefully arranged and calibrated before data collection. The string should be securely attached to the wave **generator at one end** while passing over a **low-friction pulley at the other**. The **counterweight** must be properly **measured** and **suspended** to maintain consistent tension throughout the experiment (See Figure 4). The **length** of the **vibrating portion** of the string should be measured precisely using a ruler or meter stick. Additionally, the wave generator's frequency should be adjusted gradually to locate the resonance conditions where standing waves form with well-defined nodes and antinodes. Proper **lighting** and **background contrast** can help visualize the wave motion more clearly, improving **node identification**. Finally, to minimize external disturbances, the table or surface holding the setup should remain stable and free from vibrations caused by external movements.

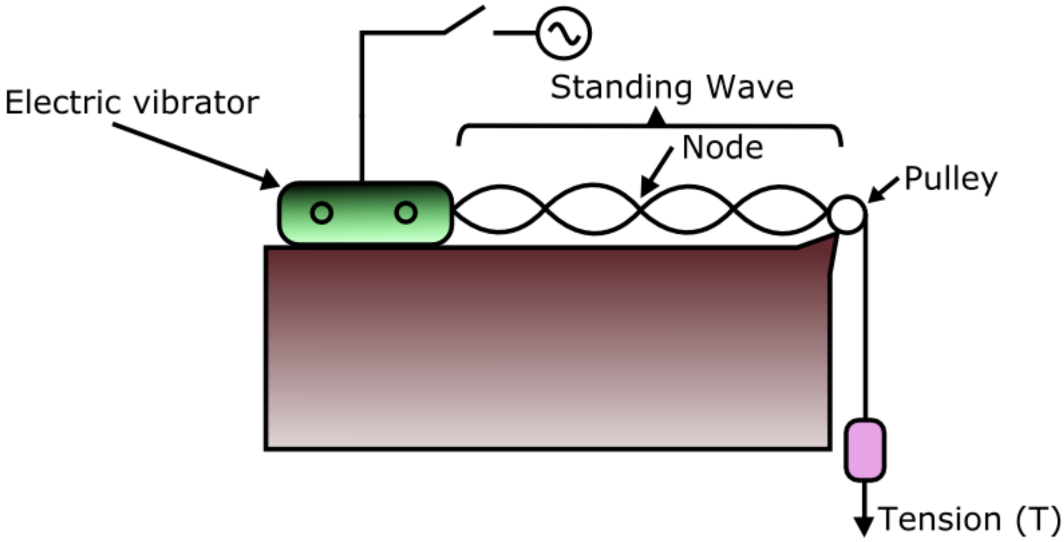
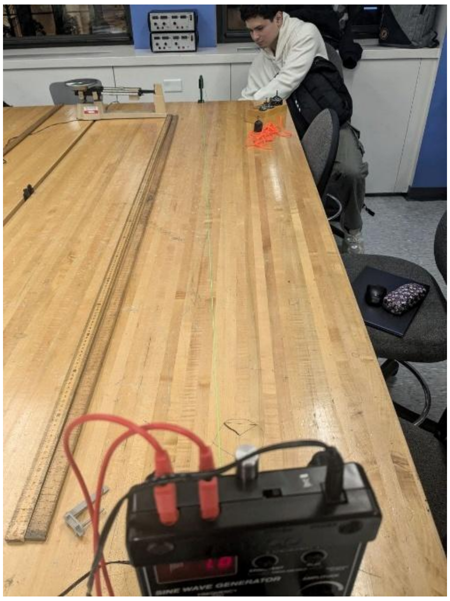
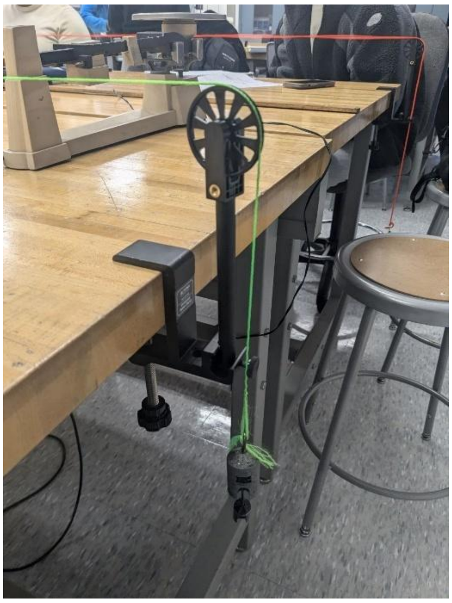



FIGURE 4. *Diagram of the experimental setup for measuring wave speed. The string is attached to a wave generator on one end and passes over a low-friction pulley before being connected to a hanging mass. The wave generator produces oscillations at varying frequencies to create standing waves along the string, while the counterweight provides the necessary tension for wave propagation.*

## EXPERIMENT:

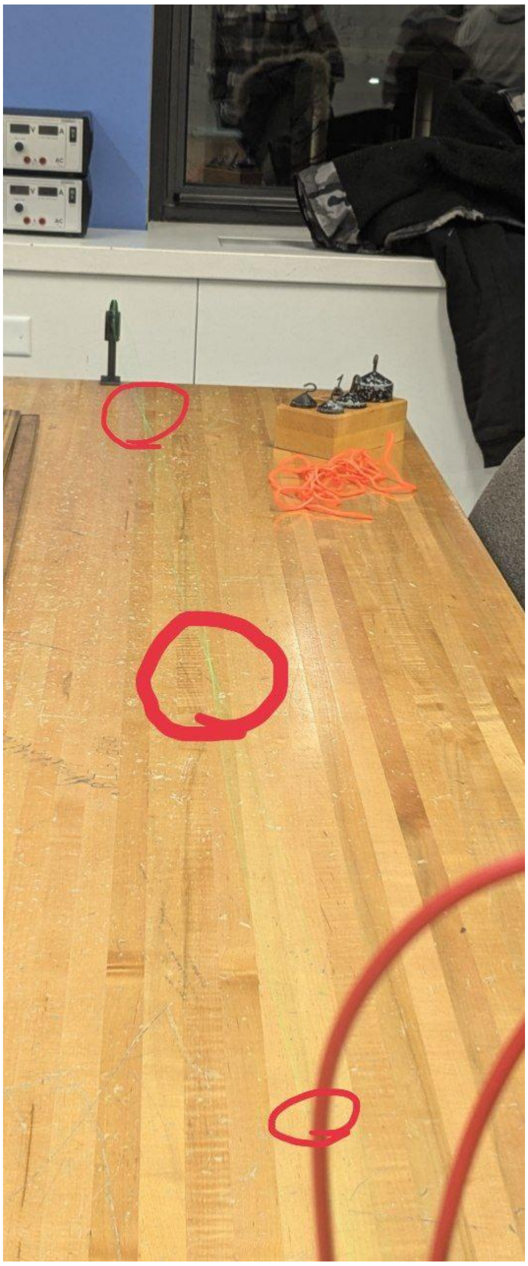
1. Secure the string to the wave generator and suspend a mass at the other end to maintain constant tension. (Figures 5 and 6)

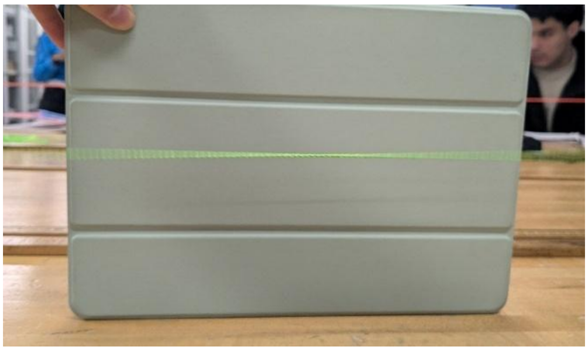




FIGURES 5 & 6. *The first image shows the wave generator exciting the string, while the second image highlights the pulley system with a suspended mass, which maintains constant tension in the string.*

2. Turn on the wave generator and adjust the frequency to observe standing waves with distinct node patterns. (Figures 7 and 8)





FIGURES 7 & 8. *Visualization of standing wave formation. The red-circled areas in Figure 7 highlight stationary nodes, while Figure 8 provides a close-up of the wave, confirming the presence of nodes and oscillating segments.*

3. Record the number of nodes and corresponding frequencies.
4. Calculate wave speed using the standing wave equation.
5. Measure the string's mass and length to determine $\mu$.
6. Compute wave speed using the second method.
7. Compare both results and analyze discrepancies.

## DATA & ANALYSIS

The collected data for different standing wave modes and calculations are shown in Tables 1 and 2.

| Mass of $l$ / kg | Length $l$ / m | Mass per Length $\mu$ | Speed v / (m/s) |
|---|---|---|---|
| 9.51E-03 | 10.13 | 9.39E-04 | 35.411 |

TABLE 1. *This table provides a comparative analysis of wave velocity derived from the mass per unit length ($\mu$) and applied tension ($F_T$). By calculating $\mu$ from the measured mass and length of the string, the wave speed was determined using the theoretical equation $v = \sqrt{\frac{F_T}{\mu}}$. The obtained velocity is then compared with the values from the standing wave method, offering insight into the consistency and accuracy of both approaches.*

| Nodes n | Wavelength $\lambda$ / m | String Length $L$ / m | Hanging Mass / m | Frequnecy $f_n$ / Hz | Speed v / (m/s) | Error % |
|---|---|---|---|---|---|---|
| 8 | 0.590 | 2.36 | 0.120 | 60.5 | 35.695 | 0.8% |
| 6 | 0.787 | 2.36 | 0.120 | 44.5 | 35.007 | 1.1% |
| 2 | 2.360 | 2.36 | 0.120 | 15.0 | 35.400 | 0.0% |
| 7 | 0.674 | 2.36 | 0.120 | 52.0 | 35.063 | 1.0% |
| 5 | 0.944 | 2.36 | 0.120 | 38.5 | 36.344 | 2.6% |
| 3 | 1.573 | 2.36 | 0.120 | 23.0 | 36.187 | 2.2% |

TABLE 2. *This table presents measured values for different standing wave modes, including the number of nodes, wavelength, string length, and applied tension. The wave speed was determined using the relationship between frequency and wavelength. The percentage error column highlights the deviation between experimental values.*

## CONCLUSION

This experiment **successfully** measured the **speed of a wave** using two distinct approaches: the standing wave method and the tension-line density method. The standing wave approach utilized measured frequencies and node patterns to determine wave velocity, while the second method relied on direct physical properties of the string, such as its mass per unit length and applied tension.

Both methods yielded **consistent results**, with an **average wave speed** of approximately **35.4 m/s**, and errors remained within a **3% margin**, indicating a reasonable level of accuracy. The primary discrepancies arose from minor uncertainties in measuring node positions, fluctuations in frequency adjustments, and assumptions regarding the uniform mass distribution of the string.

The tension-based method proved to be a more **direct and physics-based calculation**, depending only on measurable mass and length values. However, the standing wave method allowed for a more **visual and interactive** understanding of wave behaviour, reinforcing fundamental wave properties such as resonance and harmonic modes.

Future improvements could include using higher precision frequency counters to reduce uncertainties in node detection and frequency tuning. Additionally, measuring line density with a more extensive sample size could refine the accuracy of the tension-based calculation. Despite these limitations, the experiment effectively demonstrated the relationship between frequency, wavelength, and wave velocity, reinforcing the theoretical principles of wave mechanics.

## ACKNOWLEDGMENTS

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## REFERENCE LIST

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### FIGURES

Tuiachieva, Z. (2025). A sine wave generator [Figure 1].

Diagram illustrating the formation of a standing wave [Figure 2]. Retrieved from https://www.google.com/url?sa=i&url=https%3A%2F%2Fbyjus.com%2Fphysics%2Fstanding-wave-normal-mode%2F

The experimental setup where a vibrating string is tensioned by a hanging counterweight [Figure 3]. Retrieved from https://i.sstatic.net/ymVAn.gif

Experimental setup for measuring wave speed [Figure 4]. Retrieved from https://upload.wikimedia.org/wikipedia/commons/3/3c/Melde-experiment-graphic.PNG

Tuiachieva, Z. (2025). Wave generator exciting the string [Figure 5].

Tuiachieva, Z. (2025). Image highlights the pulley system with a suspended mass [Figure 6].

Tuiachieva, Z. (2025). Visualization of standing wave formation [Figure 7].

Tuiachieva, Z. (2025). Close-up of the wave [Figure 8].

## TABLES

Tuiachieva, Z., Villafan, J., & Rahman, J. (2025). Comparative analysis of wave velocity derived from the mass per unit length ($\mu$) and applied tension (F_T) [Table 1].

Tuiachieva, Z., Villafan, J., & Rahman, J. (2025). Measured values for different standing wave modes, including the number of nodes, wavelength, string length, and applied tension [Table 2].