HACETTEPE ÜNİVERSİTESİ
FİZİK MÜHENDİSLİĞİ BÖLÜMÜ

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Experiment-8: Standing Waves

HEinrich Rudolf Hertz (1857-1894, Bonn)
German physicist.

He studied physics at the University of Berlin under the directorship of Helmholtz and Kirchoff. In 1885, he was promoted to professor position in physics at the University of Karlsruhe. In 1888, he had discovered the radio waves in which area he is well known. The discovery of radio waves, demonstration of their existence and calculation of the speed of it is the most important achievements of Hertz. Following the discovery of that, the speed of radio wave was found to be same with the speed of light; Hertz showed that radio waves were capable of reflection, refraction, and interference. He made many contributions to science during his short life. *hertz* (Hz), the physical unit of frequency which is defined as number of vibrations per second, is referred to his name.

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Supervisor:

Signature:

Waves

The wave is a vibration. It carries the energy emitted from matter from one place to another.

There are two types of waves. These are Mechanical Waves and Electromagnetic Waves. Mechanical waves are studied in this experiment.

There are two types of waves. These are Transverse and Longitudinal waves. The main difference between them is that the direction of the wave and its oscillation direction are parallel in longitudinal wave. Also, Transverse waves can be polarized, but Longitudinal waves cannot be polarized.

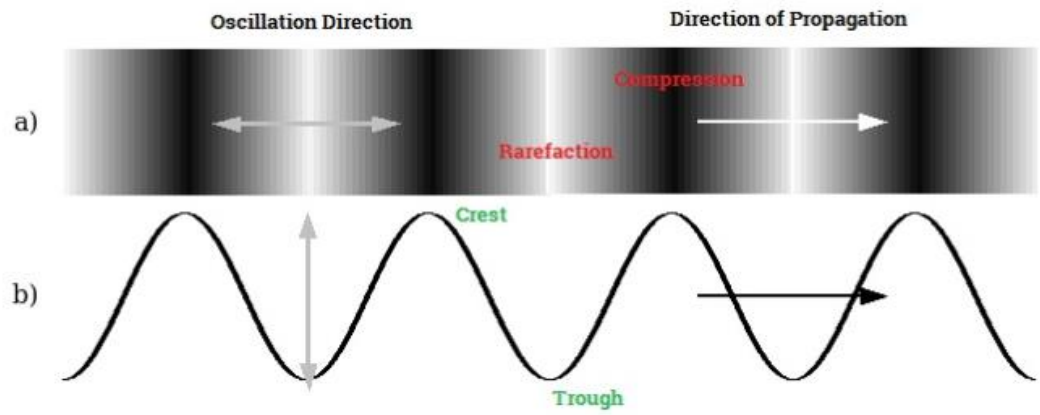
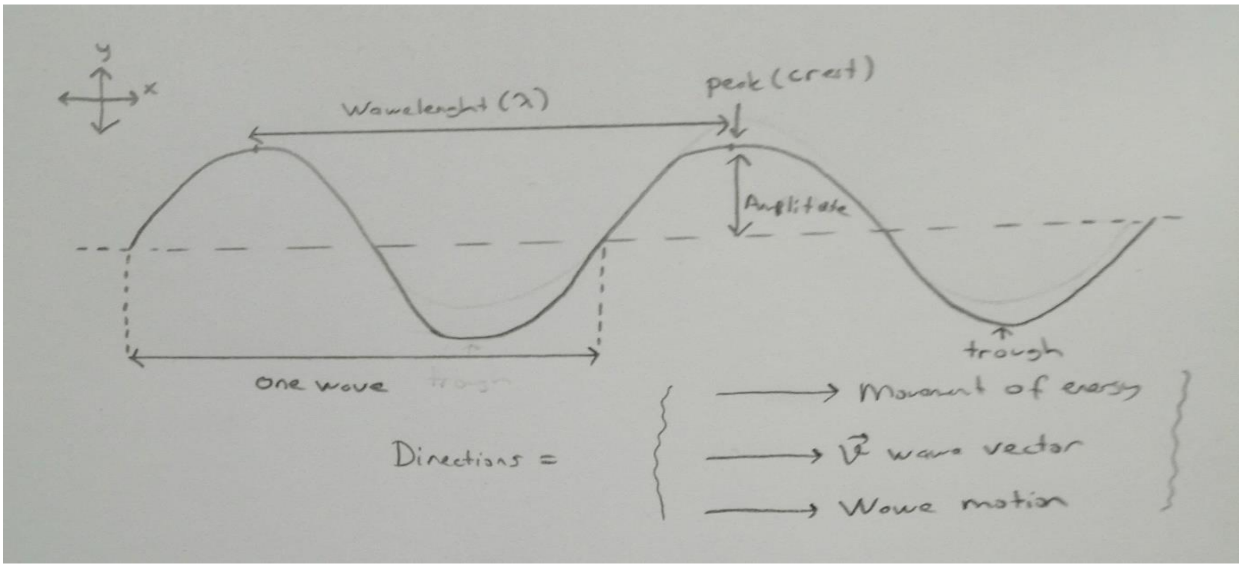


Figure 1.1 a) Longitudinal waves b): Transverse waves



- The time it takes for the wave to travel one wavelength is called the period and denoted by T.

- The number of complete waves occurring in one second is defined as the frequency.

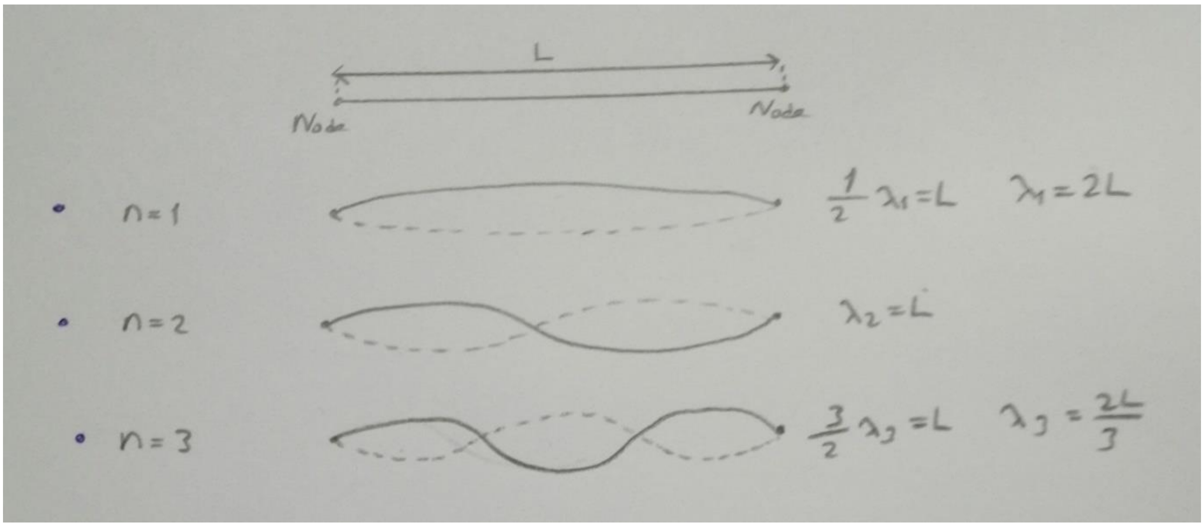
$$f = 1/T$$

- The path the wave takes in one period is called the wavelength and is denoted by λ.
- w is the angular frequency and is defined as

$$\mathbf{w = 2\pi\ f = 2\pi/T}$$

- The forward speed of the wave is defined as

$$\mathbf{v = \lambda . f}$$



- We can define the transverse velocity of the wave as shown below.

$y = A\sin(kx - \omega t)$ *(Advancing in the positive x-axis direction)*

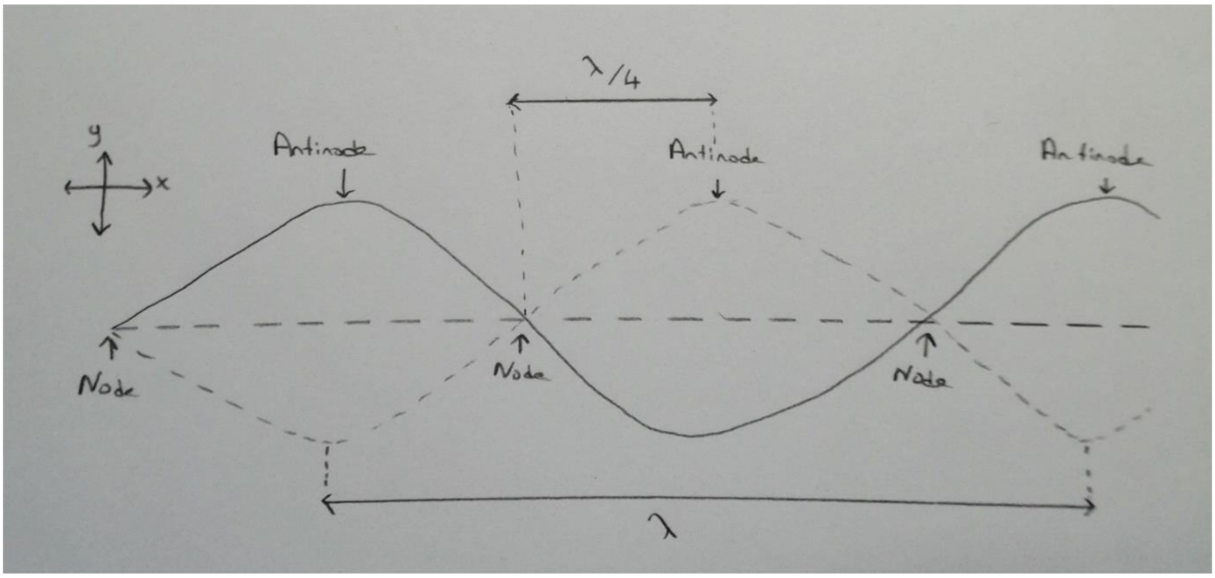
$y = A\sin(kx + \omega t)$ *(Advancing in the negative x-axis direction)*

Amplitude: A , Wawe number: k = $2\pi/\lambda$, Angular frequency: ω

- Maximum speed and maximum displacement are defined in this way.

$$v_{max} = A.\omega$$

$$x_{max} = A$$



- The distance between the two nodes is λ / 2.
- The distance between a node and an anti-node is λ / 4.

Sound waves propagating in the air

First of all, sound waves do not propagate in space. Therefore, it takes place in the material environment. Molecules in the environment vibrate and sound propagates in waves. Sound waves propagating in the air are longitudinal mechanical waves. Speed of propagation of sound waves in air is expressed as follows:

$$\mathrm{v} = \sqrt{\frac{B}{\rho}}$$

B is the bulk modulus of air (N / m2) , ρ is the density of air (kg / m3)

The Resonance Phenomenon

Resonance is the tendency of a system to oscillate at some frequencies at greater amplitudes than others. Resonance occurs when a material oscillates at a high amplitude at a certain frequency. In order for linear systems to resonate, the oscillation amplitude must be directly proportional to the applied force. If these oscillations are equal to the natural frequency of the system, the amplitude of the system tends to increase infinitely; this event is called resonance.

Section.1

Aim:

In the first part, we used a fixed rope with a fixed length of L and three different strength values. We measured the distances between two nodes with different frequency values. This value is equal to λ / 2 and we recorded it in tables. Since we know the wavelength and frequency, we calculated the wave velocities and found the average velocity. We calculated the speed of the wave with the Wavelength-Period graph. Finally, we calculated the Linear mass density values of the threads and found their differential errors.

$F = 0.5$ N

Number of half-wavelength, n	f (Hz)	$1/f$ (s)	$\lambda/2$ (cm)	λ (m)	$v = \lambda . f$ (m/s)
1	12.0	0.083	90.8	1.816	21.79
2	24.0	0.042	46.0	0.92	22.08
3	36.8	0.027	30.0	0.60	22.08
4	48.2	0.021	23.5	0.470	22.65
5	59.6	0.017	18.5	0.370	22.05
				Average speed	22.13

Calculations: ($F=0.5N$)

- The slope of Graph 1.1 $= \dfrac{\Delta\lambda}{\Delta(1/f)} = \dfrac{0.65m}{0.03s} = 21.7\ m/s = v_1$

- $v = \sqrt{\dfrac{F}{\mu}} \Rightarrow \mu_1 = v_1^2 . F = (21.7\ m/s)^2 \times (0.5N) = 235.4\ m^3.kg/s^4$

- Average speed $\Rightarrow v_{avg} = \dfrac{(21.79 + 22.08 + 22.08 + 22.65 + 22.05)\ m/s}{5} = 22.13\ m/s$

Error Calculation:

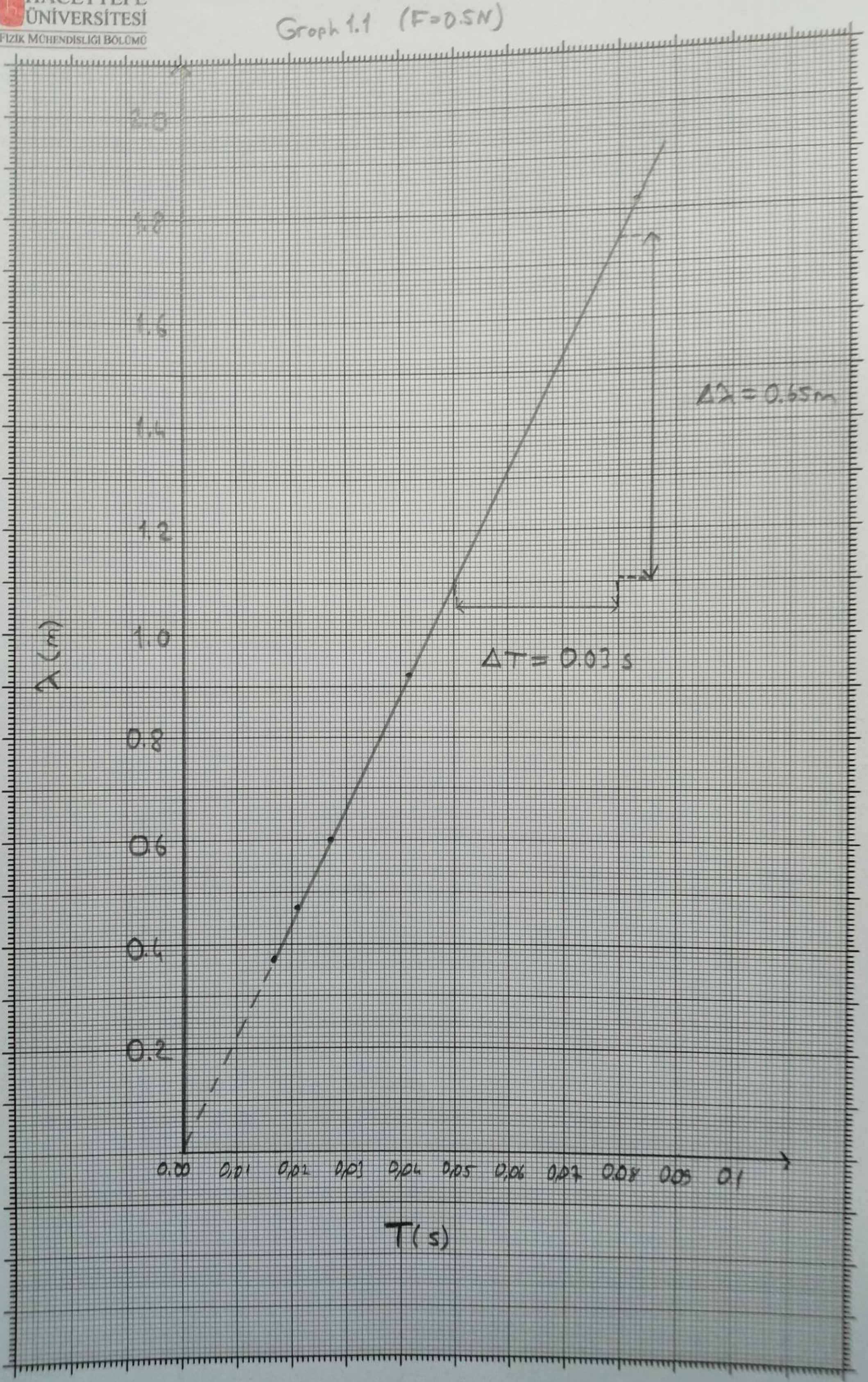
$\Delta F = 0.05N \qquad \Delta\lambda = 0.001m \qquad \Delta f = 0.1\ Hz$

$$\Delta\mu = \mu_1 \sqrt{\left(\frac{\Delta F}{F}\right)^2 + 4\left(\frac{\Delta\lambda}{\lambda}\right)^2 + 4\left(\frac{\Delta f}{f}\right)^2}$$

$$\Delta\mu = 235.4\ m^3kg/s^4 \times \sqrt{\left(\frac{0.05N}{0.5N}\right)^2 + 4\left(\frac{0.001m}{0.60m}\right)^2 + 4\left(\frac{0.1\ Hz}{36.8\ Hz}\right)^2}$$

$$\Delta\mu = 235.4\ m^3kg/s^4 \times 0.1002 = 23.58\ m^3kg/s^4$$

- $\mu = 235.4 \pm 23.58\ m^3kg/s^4$


Graph 1.1 (F=0.5N)
λ (m)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.00
0,01
0,02
0,03
0,04
0,05
0,06
0,07
0.08
0.09
0.1
T(s)
Δλ = 0.65m
ΔT = 0.03 s

$F = 1.0$ N

Number of half-wavelength, n	f (Hz)	$1/f$ (s)	$\lambda/2$ (cm)	λ (m)	$v = \lambda . f$ (m/s)
1	16.0	0.0625	90.8	1.816	29.06
2	32.1	0.0312	45.8	0.916	29.40
3	48,4	0.0207	30.4	0.608	29.43
4	63.9	0.0156	22.9	0.458	29.27
5	79.8	0.0125	18.3	0.366	29.21
				Average speed	29.27

Calculations: ($F=1.0\,N$)

- The slope of Graph 1.2 = $\dfrac{\Delta\lambda}{\Delta(1/f)} = \dfrac{0.95\,m}{0.033\,s} = 28.79\,m/s = v_2$

- $\mu_2 = v_2^2 \cdot F_2 = (28.79\,m/s)^2 \times (1.0\,N) = 828.9\ m^3 kg/s^4$

- Average speed = $\dfrac{(29.06 + 29.40 + 29.43 + 29.27 + 29.21)\,m/s}{5} = 29.27\,m/s = v_{ort}$

Error Calculations:

$$\Delta\mu = 828.9\,m^3 kg/s^4 \times \sqrt{\left(\frac{0.05\,N}{1.0\,N}\right)^2 + 4\left(\frac{0.001\,m}{0.608\,m}\right)^2 + 4\left(\frac{0.1\,Hz}{48.4\,Hz}\right)^2}$$

$$\Delta\mu = 828.9\,m^3 kg/s^4 \times 0.0503 = 41.69\ m^3 kg/s^4$$

- $\mu = 828.9 \pm 41.69\ m^3 kg/s^4$

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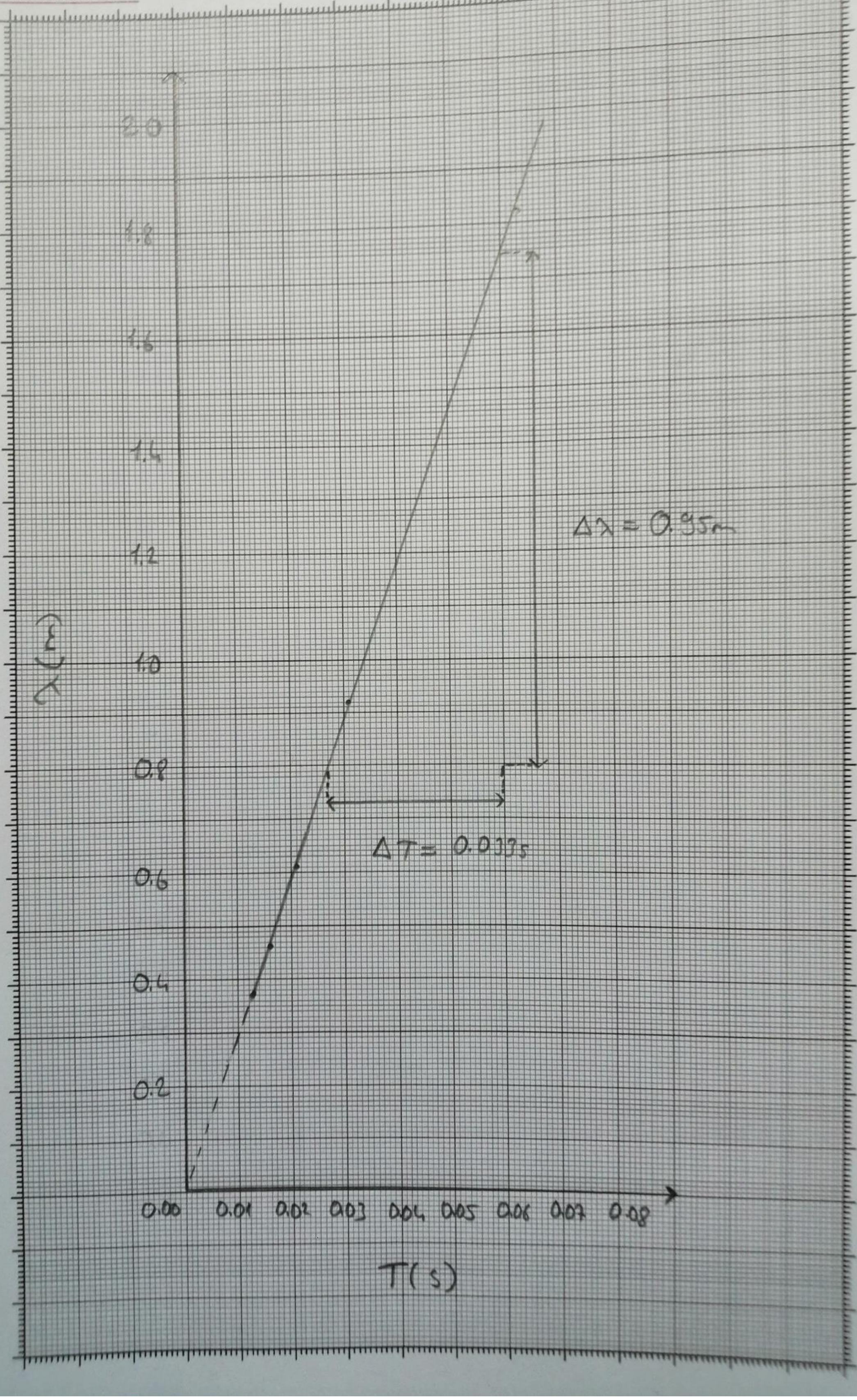
Graph 1.2 (F=1.0N)



$F = 1.5$ N

Number of half-wavelength, n	f (Hz)	$1/f$ (s)	$\lambda/2$ (cm)	λ (m)	$v = \lambda . f$ (m/s)
1	20.4	0.0490	91.0	1.820	37.13
2	40.7	0.0246	45.6	0.912	37.12
3	61.0	0.0164	30.4	0.608	37.09
4	81.6	0.0123	22.8	0.456	37.21
5	102.0	0.0098	18.2	0.364	37.13
				Average speed	37.14

Calculations: $(F = 1.5N)$

- The slope of Graph 1.3 $= \dfrac{\Delta\lambda}{\Delta(1/f)} = \dfrac{0.9m}{0.0235s} = 38.30\, m/s = v_3$

- $\mu_3 = v_3^2 . F_3 = (38.30 m/s)^2 \times (1.5N) = 2.200.3\ m^3 kg/s^4$

- Average speed $= V_{avg}^{2} = \dfrac{(37.13 + 37.12 + 37.09 + 37.21 + 37.13)\, m/s}{5} = 37.14\, m/s$

Error Calculations:

$$\Delta\mu = 2.200.3\, m^3 kg/s^4 \times \sqrt{\left(\frac{0.05N}{1.5N}\right)^2 + 4\left(\frac{0.001m}{0.608m}\right)^2 + 4\left(\frac{0.1Hz}{61.0Hz}\right)^2}$$

$$\Delta\mu = 2.200.3\, m^3 kg/s^4 \times 0.0337 = 74.15\, m^3 kg/s^4$$

- $\mu = 2.200.3 \pm 74.15\ m^3.kg/s^4$

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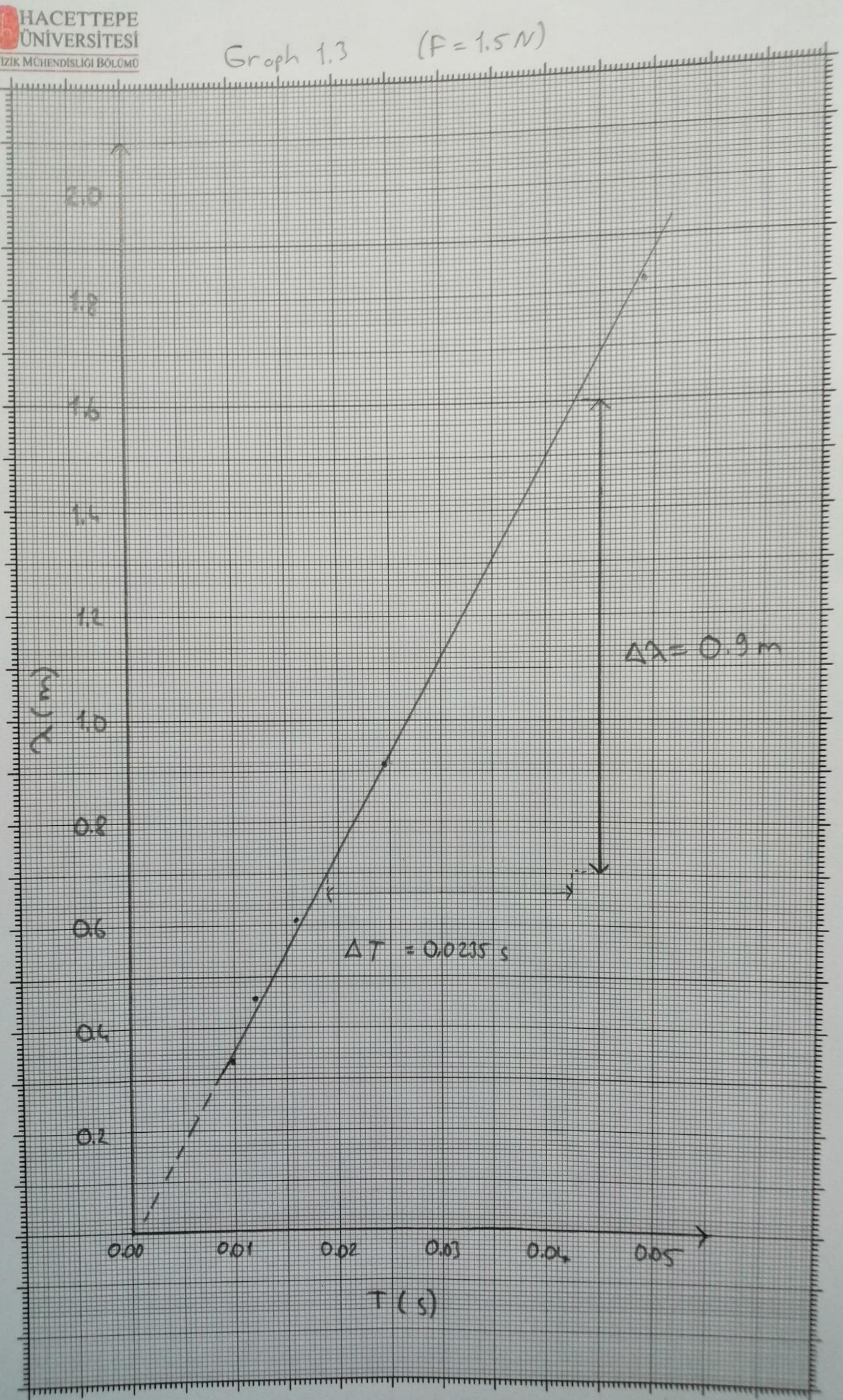

Section.2

Aim:

In the second part, sound waves are examined. The aim here is to determine the speed of sound. In order to give more accurate results, the experiment is carried out by measuring wavelengths at different frequency values. Sound waves aren’t visible to the eye, so wavelength measurement is done with a Kundt tube. Since we know the wavelength and frequency, we calculated the wave velocities and found the average velocity. We calculated the speed of the wave with the Wavelength-Period graph. Finally, with the theoretical sound velocity (343.2m / s), we calculated the percent error calculation and differential errors of the experimental sound velocity.

f (Hz)	$1/f$ (10^{-4} s)	$\lambda/2$ (cm)	λ (m)	$v = \lambda . f$ (m/s)
900	11.11	19.2	0.384	345.6
1000	10.00	17.3	0.346	346
1100	9.09	15.7	0.314	345.4
1200	8.33	14.4	0.288	345.6
1300	7.69	13.3	0.266	345.8
			Average speed of sound	345.7

Calculations:

- The slope of Graph 2.1 $= \dfrac{\Delta\lambda}{\Delta(1/f)} = \dfrac{0.084\,m}{2.4\times10^{-4}\,s} = 350\,m/s = v$

Percentage Error Calculations:

$$\% \text{ error} = \frac{|v_{theorical} - v_{experimental}|}{v_{theorical}} \times 100$$

$\boxed{v_{theorical} = 343.2\,m/s}$

- $\% \text{ error} = \dfrac{|343.2\,m/s - 350\,m/s|}{343.2\,m/s} \times 100 = \%1.98$

Differential Error Calculations:

$\Delta f = 1\,Hz \qquad \Delta\lambda = 0.001\,m$

$$\Delta v = v \times \sqrt{\left(\frac{\Delta f}{f}\right)^2 + \left(\frac{\Delta\lambda}{\lambda}\right)^2}$$

$$\Delta v = 345.4\,m/s \sqrt{\left(\frac{1\,Hz}{1100\,Hz}\right)^2 + \left(\frac{0.001\,m}{0.314\,m}\right)^2} = 1.1\,m/s$$

- $v = 345.4 \pm 1.1\,m/s$

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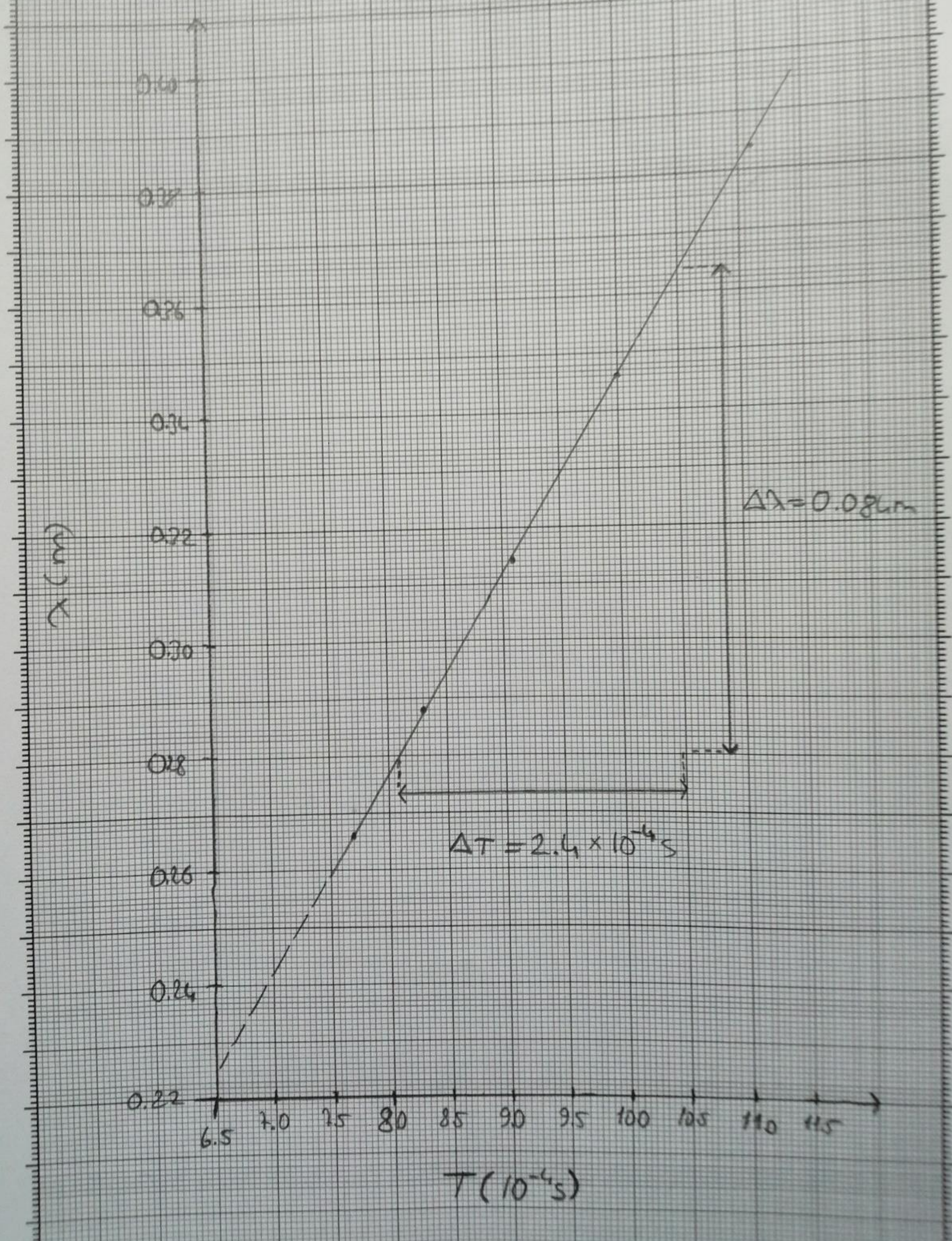
Graph 2.1



CONCLUSION

In the first part, our aim is to observe waves resting on a stretched rope. When we look for three different tables, the similarity ratio between the speed in the slope of the graph and the average speed is between 1% and 4%. We used the 3rd values in the experiment while calculating the differential error. In the experiment, as the restoring forces (F) increased, the differential errors in the linear mass density value gradually decreased. We can reduce these error rates by measuring the ΔF value more precisely. As the frequency value increases in the experiment, the number of waves formed increases. In this process, the measured wavelengths are decreasing. While measuring, the distance between two nodes should be measured carefully, so an electronic ruler can be used instead of a wooden ruler.

In the second part, our aim is to measure the speed of sound in the air. We did this with a glass tube with one end closed. In the calculation of theoretical sound velocity and experimental sound velocity, we have a value of 1.98%. If the frequency sensitivity rate is less and the distances where the sound waves overlap are calculated better, the error rate may fall below 1%. While calculating the differential error, we used the 3rd value in the experiment and found the value of $\pm$ 1.1m / s. The way to reduce the size here is to decrease the Δf (1Hz) value. In addition, the tube used in the experiment should not be affected by external intervention, that is, there should be only the sound from the source in the environment. There should be no loss or increase in the resonance process.

Finally, the waves were studied throughout the experiment. The velocity theory and the Kundt tube mechanism have been found to work correctly. It has been observed that the calculated error rates are acceptable. The experiment fulfilled its objectives.