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Research Article

Decorative Flame Behavior Study in Visualizing Wavelengths and Frequency: Ruben's Tube Construction Experiment

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Abstract: Sound waves are persistent in everyday life, although they are never seen. The particles of the average vibrations are parallel to the direction of propagation of the wave. In this article, the effect of changing the frequency of the sound wave on standing waves was investigated with different hertz frequencies to show technical images that can be visually translated to give fundamental predictions about the origin of the musical combinations, as it was proved that the sound is a pressure wave by giving the vibrations one side. At the same time, the gas is released on the other side. The variables were fixed in the experiment as the type of gas supplied for the same experiments to obtain accurate results. It is also installed so that the distance between the diaphragm and the amplifier does not differ. The results analyzed after numerous data collection and calculations verify that the generated wavelength and frequency are directly proportional. As the frequency specified in Hz increased, the number of inverse nodes and nodes also increased. Obtaining standing waves helps to understand the nature of sound as a pressure wave and give all the details about the experiment and evaluate it. Sources of error and possible solutions to overcome these problems are also mentioned.

Keywords: Dancing Flame, Ruben's Tube, Standing Wave, Music, Nodes and Antinodes

1. Introduction

In physics, the sound is an automatic frequency, or wave, that can move in a medium such as air, solid bodies, liquids, and gases, and does not propagate into a vacuum [1]. Therefore, only sound waves with frequencies between about 20 Hz and 20 kHz, the frequency band of sound, stimulate auditory perception in humans. Sound waves greater than 20kHz are known as ultrasonic and cannot be heard by humans. Sound waves below 20 Hz are known as infrasonic [2].

These waves can be visualized using a Ruben's Tube, in which a gas is ignited inside a long metal tube with a set of small holes drilled on top. The flame height is proportional to the rate of gas flow through the hole in the Tube, which can change the flame height by adjusting the gas pressure inside the Tube with a suitable choice of sound waves [3]. Standing waves can be created inside the Tube, resulting in the flame pattern. Thus, the relationships between sound waves and the shape of the flame formed can be studied [4].

Few articles have written about the behavior of the Rubens column, which was created in the early 20th century, even though it is still well documented. This is likely because the Tube is intended to demonstrate relatively simple physics; thus, few have taken the time to

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study its behaviour thoroughly. The most notable exception is Ficken and Stephenson [5], who used a directly coupled loudspeaker to drive their flame tube and demonstrated that flame maxima occur at pressure nodes and flame minima at pressure antinodes. They explained this result using Bernoulli's equation, which states that the pressure nodes have the highest time-averaged mass flow rate of the gas. They demonstrated, however, that when static gas pressures inside the Tube are low or acoustic amplitudes are large, the effect reverses, with flame minima occurring at pressure nodes and flame maxima occurring at pressure antinodes. This phenomenon remains unexplained and may be the subject of future research.

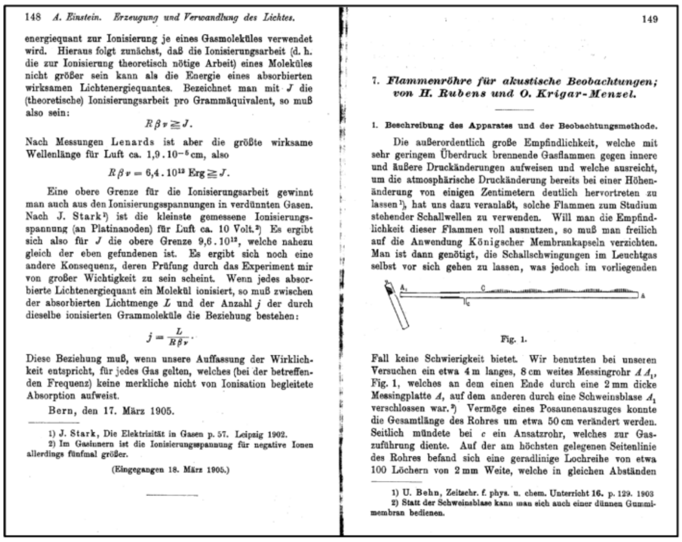
In addition to the work of Ficken and Stephenson [5], other brief studies on various aspects of the Tube's behavior have been conducted. A few different relationships need to be studied when flames of different temperatures are put in the same gas-expanded chamber. One of these is between flame height and pressure [6]. Although his results were only preliminary, he undertook to determine the phase relationship between the loudspeaker's flicker and the flame's characteristics, and he had limited success [7]. Two-dimensional modal table expansions directly trace back to Daw [8], [9], who was a professor of Visual Construction and Performance for 25 years and produced work including flat flame table maps and the also circular ones used for modelling two-The longevity of Rubens and Krigar-Menzel's is a running parallel to that of visual construction and performance patterns.

This investigation aims to prove that the sound is a pressure wave and to know the relationship between the length and the wavelength of the standing waves using a closed tube, one end and the other connected via a loudspeaker. The Tube used in the experiment is called Ruben's Tube. That instantaneous image capture aided in the investigation of inverse node amplitudes and wavelengths .The Ruben's Tube is precisely like a loudspeaker when both observe the effect of changing frequency. The frequency change in both affects the wavelength of the sound wave.

Further examination of Ruben's Tube gave the idea to investigate the effect of sound waves on standing waves. To narrow it down a little more decided to analyze the relationship between frequency and wavelength. Defining the relationship between these two properties of a sound wave will also prove that a sound wave is a pressure wave [10].

2. A Brief Information of Ruben's Tube

In 1905, *Annalen der Physik* published an article that influenced millions of science students. Einstein's famous article on the photoelectric effect, but to a seemingly innocuous paper that appeared immediately after Einstein's famous article. Heinrich Rubens and Otto Krigar-Menzel [11] discussed the development and underlying principles of a physics demonstration known variously as the "Rubens tube," "flame tube," and "standing wave flame tube" in the article. It should be noted that Rubens had previously published an initial description of the tube in 1904 [12]. Figure 1 shows the last page of Einstein's article and the first page of Rubens and Krigar- Menzel's article.



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energiequant zur Ionisierung je eines Gasmoleküles verwendet wird. Hieraus folgt zunächst, daß die Ionisierungsarbeit (d. h. die zur Ionisierung theoretisch nötige Arbeit) eines Moleküles nicht größer sein kann als die Energie eines absorbierten wirksamen Lichtenergiequantes. Bezeichnet man mit J die (theoretische) Ionisierungsarbeit pro Grammäquivalent, so muß also sein:

$$R\beta\nu \geqq J.$$

Nach Messungen Lenards ist aber die größte wirksame Wellenlänge für Luft ca. $1,9 \cdot 10^{-5}$ cm, also

$$R\beta\nu = 6,4 \cdot 10^{12}\ \mathrm{Erg} \geqq J.$$

Eine obere Grenze für die Ionisierungsarbeit gewinnt man auch aus den Ionisierungsspannungen in verdünnten Gasen. Nach J. Stark[1]) ist die kleinste gemessene Ionisierungsspannung (an Platinanoden) für Luft ca. 10 Volt.[2]) Es ergibt sich also für J die obere Grenze $9,6 \cdot 10^{12}$, welche nahezu gleich der eben gefundenen ist. Es ergibt sich noch eine andere Konsequenz, deren Prüfung durch das Experiment mir von großer Wichtigkeit zu sein scheint. Wenn jedes absorbierte Lichtenergiequant ein Molekül ionisiert, so muß zwischen der absorbierten Lichtmenge L und der Anzahl j der durch dieselbe ionisierten Grammoleküle die Beziehung bestehen:

$$j = \frac{L}{R\beta\nu}.$$

Diese Beziehung muß, wenn unsere Auffassung der Wirklichkeit entspricht, für jedes Gas gelten, welches (bei der betreffenden Frequenz) keine merkliche nicht von Ionisation begleitete Absorption aufweist.

Bern, den 17. März 1905.

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1) J. Stark, Die Elektrizität in Gasen p. 57. Leipzig 1902.

2) Im Gasinnern ist die Ionisierungsspannung für negative Ionen allerdings fünfmal größer.

(Eingegangen 18. März 1905.)

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7. ***Flammenröhre für akustische Beobachtungen; von H. Rubens und O. Krigar-Menzel.***

1. Beschreibung des Apparates und der Beobachtungsmethode.

Die außerordentlich große Empfindlichkeit, welche mit sehr geringem Überdruck brennende Gasflammen gegen innere und äußere Druckänderungen aufweisen und welche ausreicht, um die atmosphärische Druckänderung bereits bei einer Höhenänderung von einigen Zentimetern deutlich hervortreten zu lassen[1]), hat uns dazu veranlaßt, solche Flammen zum Studium stehender Schallwellen zu verwenden. Will man die Empfindlichkeit dieser Flammen voll ausnutzen, so muß man freilich auf die Anwendung Königscher Membrankapseln verzichten. Man ist dann genötigt, die Schallschwingungen im Leuchtgas selbst vor sich gehen zu lassen, was jedoch im vorliegenden Fall keine Schwierigkeit bietet. Wir benutzten bei unseren Versuchen ein etwa 4 m langes, 8 cm weites Messingrohr AA_1, Fig. 1, welches an dem einen Ende durch eine 2 mm dicke Messingplatte A, auf dem anderen durch eine Schweinsblase A_1 verschlossen war.[2]) Vermöge eines Posaunenauszuges konnte die Gesamtlänge des Rohres um etwa 50 cm verändert werden. Seitlich mündete bei c ein Ansatzrohr, welches zur Gaszuführung diente. Auf der am höchsten gelegenen Seitenlinie des Rohres befand sich eine geradlinige Lochreihe von etwa 100 Löchern von 2 mm Weite, welche in gleichen Abständen

Fig. 1.

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1) U. Behn, Zeitschr. f. phys. u. chem. Unterricht 16. p. 129. 1903

2) Statt der Schweinsblase kann man sich auch einer dünnen Gummimembran bedienen.

Figure 1. The Last Page of Einstein's and the First Page of Rubens and Krigar- Menzel's Article [13].

Ruben's Tube is a classic physical device to show that sound waves mainly compress waves and give a visual display of waves standing by a flame. In 1905, the German scientist Heinrich Rubens invented the original device four meters long from a tube with 200 holes of equal diameters distributed steadily along its length [14]. The Tube ends were closed, and flammable gas pumped into it, and the gas escaped from the holes and then lit up to form flames with the same height as shown in Figure 1.

A loudspeaker was connected to one end of the device, and the sound was played at frequencies at which the flame heights changed, illustrating the pressure differences created inside the tube due to the sound waves [15]. As soon as the gas is ignited within the Rubens' tube generally, uniform flames will be seen. This is because there is a minimal pressure differential between any given area of the space inside the tube. However, once the sound is applied from one end, pressure will change within the tube. Thus, should the sound be an easily measurable frequency, the wavelength will be visible in the series of flames, with the highest flames being where condensation is occurring and the lowest where rarefaction is occurring.

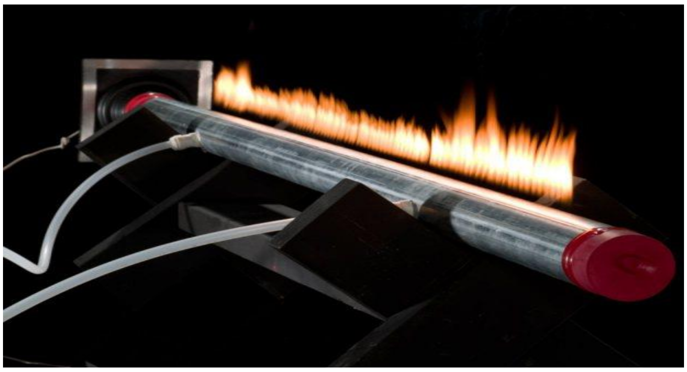

Figure 2. Ruben's Tube Construction

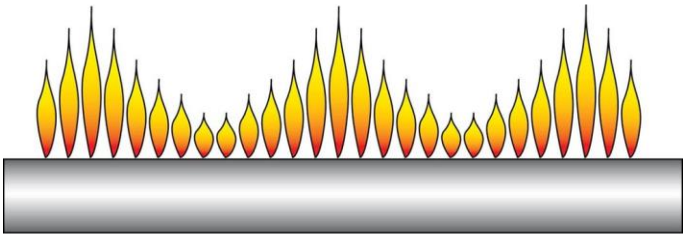

Figure 3. Rubens' Tube under normal conditions

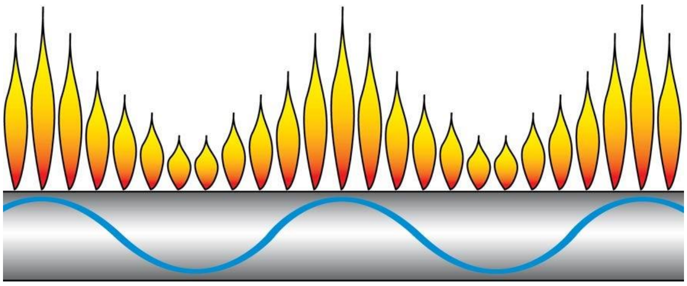

Figure 4. Rubens' Tube under sine wave of the tone

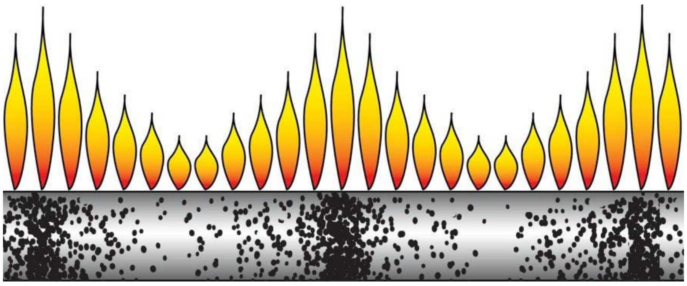

Figure 5. Rubens' Tube under pressure changes as a compressional wave

The first image represents a functioning Rubens' Tube under normal conditions. Assume that in this image, an arbitrary, constant tone is being played into one end of the tube. However, what might we witness if we could peer inside the tube and see the sound waves?.

The following image gives us an idea of what is going on if we could see the sine wave of the tone. Nevertheless, what is critical to remember is that what is occurring is a change in pressure between different waveform amplitudes.

The final image illustrates these pressure changes as a compressional wave. Understanding sound in the way makes it clear as to why we have the varying flame height. The taller flames correspond directly with, the higher pressure. This higher pressure in the compressional wave is what is pushing the gas out of the holes with more force than in the areas with lower pressure [16].

3. Research Methods

3.1. Experiment Setup

Before starting the experiment, it must be ensured that no gas leak may be a risk to the safety of the work by connecting the Tube of the gas burner and the right end of the Tube that contains the hole together. The gas is run for 20 seconds to fill the Tube, and then the upper part of the perforated Tube is ignited. If not, the gas could leak from somewhere other than the vents, and all fixtures could catch fire. The amplifier is placed near its end along with the Tube's rubber membrane. It is connected to a frequency generator. Audacity is used as a frequency generator in this experiment, as shown in Figure 6 and Figure 7. Audacity capable resonant frequencies are generated in order to produce perfectly shaped standing waves. The gas pressure is adjusted to produce better standing waves. The room temperature was measured for each different frequency and used to calculate the speed of sound with higher accuracy, with the above procedures being repeated for each frequency. The experiment was continued until a spectrum of data was collected.

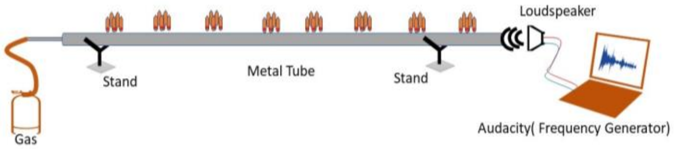

Figure 6. Setup of Experimental

Figure 7. Photographic Experimental System

In this paper, an open-ended cylindrical aluminum tube, 200 cm long and 10 cm in diameter, was used. Small circular holes of 0.20 cm in diameter and 15 cm apart were made between the one and the next, along the same Tube length. We work to close one end of the tube with a piece of rubber membrane that works to save the gas from leakage to the outside, and install the gas burner tube on the other end, and install the Tube on support to prevent any unexpected movement.

3.2. Controlling of Variables

In this experiment, an independent variable is a frequency, while the dependent variable is the effect of the frequency on the standing waves that appear. Therefore, there must be the possibility of controlling the variables to study their effect on the frequency change on the standing waves.

- Room Temperature

One of the most important effects on the speed of sound is the ambient temperature. The speed of sound is 340.29 m/s at sea level, but the experiment is conducted in a laboratory, so the temperature affects the calculations and results as follows [17]:

$$v = [(331.5 \pm 1\, m/s) + (0.6 \pm 0.1\, m/s°C)\, T_c] \qquad (1)$$

T_c= Temperature in Celsius

- Length of the Tube

Standing waves occur in moving media and are calculated to reach the best value of the generated frequency, as the length of the used Tube is proportional to the resulting wavelength. In the experiment, a tube with a length of 200 cm was used, and holes were made 15 cm from the ends of the tube to prevent the effect of the conduction temperature on the ends of the connection in the Tube. The equation below shows the relationship between the length of the Tube and the generated wavelength. For a tube with a closed end and an open end, all frequencies with n represent an odd integer considered standard frequencies where the odd fundamental harmonics are the typical frequencies [18].

$$\lambda = \frac{4L}{n} \qquad (2)$$

λ = Wavelength
L = Tube length
n = 1, 3, 5, ...

- Number of Antinodes and Nodes

There is a direct correlation between frequency, the number of nodes and antinodes, and the increasing frequency generated. The decrease in the wavelength of a wave causes more standing waves to be produced. The formula calculates wavelength; Where none is less than the total number of nodes and antinodes because one end of the Tube is open, the number of nodes and antinodes are equal. Where the wave begins with a node and ends with an antinode. The equation of speed of sound relates to the wavelength and the frequency.

$$f = \frac{v}{\lambda} \qquad (3)$$

f = Frequency (Hz)
V = Sound speed (m/s)
λ = Wavelength (meter)

In Equation 3, the wavelength and frequency are inversely proportional, while the frequency of the generated wave, the number of nodes and antinodes are directly proportional.

In the experiment, it is possible to determine the number of antinodes and nodes through calculations. If the number of inverse nodes is not as much as the expected value, the accounts are reviewed, and the experiment is repeated to identify errors in the calculations due to differences between the expected number and the observed number.

4. Result and Discussions

4.1. Data Collected and Calculated

The table below shows the value of the generated frequency for each wavelength to get the best standing waves, where the inputs are:

Room Temperature = 19.1 ±0.2 °C
Speed of sound = 343.2 ± 0.1 m/s
Tube's length = 1.80 ± 0.02 m

$$\%\ of\ error = \frac{|Measured - Actual|}{Actual} \times 100 \qquad (4)$$

$$Average\ \%\ of\ error = \frac{Sum\ of\ \%\ Errors}{Number\ of\ trials} \times 100 \qquad (5)$$

Ruben's Tube test and see the most visible range of frequencies selected. Once the experimental mean was found, a percentage error analysis was performed. Since the experimental value was more significant than the expected value in some cases, the percentage is expected to be negative. The percentage of error for all wavelengths except 600 Hz remained between -5% and 5% (see Table 2). The higher percentage error of 600 Hz can be attributed to the fact that it was the less specific curve; Therefore, the chance of human error was much more significant in the wavelength measurement. Other causes of the margin of error could be air, such as from air conditioning; due to the visual effect on the flame, the air conditioner was covered before continuing the experiment.

Table 1. Calculated and Actual Data for The Experiment

Number of nodes+ antinodes	1+1	2+2	3+3	4+4
Estimated (actual) frequency (Hz)	47.7	143.0	239.0	334.0
Percentage Error (%)	4.19	143.0	4.60	4.79
Wavelength (m)	7.20	2.40	1.44	1.03
Generated frequency for the best standing waves (Hz)	45.4	137.0	228.0	318.0
Average Percentage Error (%)				3.41

From the data collected during the experiment period, we note that the generated frequencies have an average error of 3.41%, which is calculated by comparing the computed data and the best frequency produced during the experiment. After entering the scheduled data into Logger Pro, a spreadsheet program, Figure 8 is obtained as shown below. Indicating the wavelength against the frequency graph, we notice that it is gradually decreasing as it shows the inverse ratio between the wavelength and the frequency of the obtained wave. At the same time, the wavelength decreases, and the frequency increases according to the graph. Since the wavelength, the number of nodes and the antinodes are inversely proportional, and it can be concluded that the number of nodes and antinodes are directly proportional to the frequency.

Table 2. The Wavelengths of The Selected Frequencies and The Error Analysis Were Given in Percent.

Frequency	Trial 1	Trial 2	Trial 3	Average	Expected	% Error
300 Hz	78 cm	83 cm	79 cm	80 cm	78 cm	-2.5%
400 Hz	54 cm	63 cm	55 cm	57.33 cm	59 cm	2.83%
500 Hz	51 cm	49 cm	47 cm	49 cm	47 cm	-4.26%
600 Hz	28 cm	45 cm	36 cm	36.33 cm	39 cm	6.85%
700 Hz	30 cm	37 cm	39 cm	35.33 cm	34 cm	-3.91%

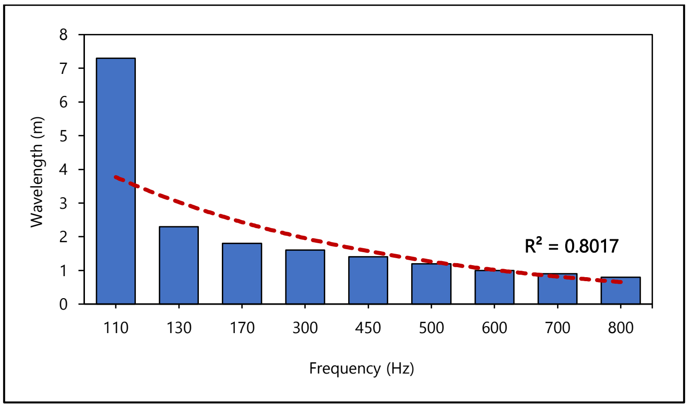

Figure 8. Frequency vs Wavelength Graph

The results obtained within the experiment are accurate, with a mean percentage error of 3.41%; however, on the graph, a direct line could not be obtained; therefore, the best-fit line is drawn. As a result, the points on the graph deviate from the most direct fit line on some points. In addition, there are some errors within the experiment which has caused the share error of 3.41%. Those errors would be:

- The formula to determine the speed of sound in temperature may have entirely failed due to the no adjustment of the effect of unknown humidity since it has taken into consideration. Another formula would be used to beat this problem that the humidity is added into calculation too; however, the experiment must be held during a lab that features a hygrometer.
- The standard process within the lab may have affected the results. For example, fire has been wonted to observed the standing waves. As a result of using fire, the space temperature has risen a touch after a short time. In the planning stage of the experiment, the temperature has been planned to be checked after each trial. Therefore, the temperature is checked; however, a significant change has not been observed on the thermometer. To not have such a mistaken source, more sensitive thermometers should be obtained and checked regularly before each trial, and

calculations should be made accurately, supported the natural process.

- Expansion may have occurred on the Tube because it has been heated for an extended time; however, this can be a small source of error due to the high expansion heat of the fabric used for the Tube. To beat such a probable source of error, after each trial tube could be cooled down, this is often not a simple thing to try to so this source of error might be neglected.
- The possibility of using the manufactured system to show unique artistic images in harmony with sound waves travelling to the flame at various frequencies can be used in national festivals (the Iraqi national anthem), celebrations, and all musical events are giving a visual artistic character.

5. Conclusion

The results obtained from the experiment that the wavelength and frequency generated in the Tube are inversely proportional because the change in frequency has affected the wavelength.

$f = V / \lambda$

$\lambda = 4 L / n$

Since the given formulas compute the actual values, the total formula is $f = vn/4L$. Since the experimental setup is based on a Ruben's Tube, it is considered a tube sealed on both ends. The sound wave begins in the closed Tube with one end of the node and ends with the antinodes, and thus in the formula, n is one less than the total number of nodes and antinodes in the wave. The velocity of sound is calculated in order to find the value of V. The value of L was the length of the Tube in meters; however, the non-arched portions of the Tube are replaced by the total length because in those parts, no air will escape and therefore no gas will escape.

Also, the sound was considered a pressure wave in the experiment, as it was observed that the pressure regions cause the gas to be pushed out with less force at the node than the antinode. When the generated frequency increases, the flame height rises successfully because as the frequency increases, the gas molecules are compressed together with a greater force and thus, the flames rise. During the experiment, it was observed that the standing wave had a knot so that the flames were small. When the gas pressure is constant, the high sound frequency of the speaker produces high flames in the nodes, and the low sound frequency causes low flames in the nodes. When the sound intensity is constant, the flames are highest at the antinode of the standing wave. As a result, when the gas pressure is low, and the sound pressure is high, the atmospheric pressure can be absorbed into the Tube. With the help of these observations, it can be concluded that sound is a pressure wave and a longitudinal wave.

Acknowledgments

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