Physics Extended Essay

A research about the effect of sound waves on standing waves by using Ruben’s Tube.

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Abstract

Sound waves are longitudinal waves. In a longitudinal wave, particles of medium vibrations are paralel to the direction of propagation of the wave. Using this nature of sound waves, Ruben's tube has been created. In Ruben's Tube, by the help of pressure, standing waves are created. In this extended essay, I investigated the effect of frequency change of a sound wave on standing waves. Also by doing such an experiment I have also proved that sound is a pressure wave too since vibrations are given into a tube while gas is given from the other side.

To acquire accurate results, variables in the experiment have been made constant (controlled) such as the type of gas given which is natural gas into the tube and the same tube is used for all trials. Loudspeakers have not been changed or not moved in order not to differ the distance between the membrane and the speaker.

The analyzed results after several data collection and calculations verify that the wavelength and the frequency generated are directly proportional. As the frequency given increased in hertz, the number of antinodes and nodes increased too. Therefore when the number of nodes and antinodes increases, wavelength decreases which shows the inverse relation between wavelength and frequency.

Obtaining standing waves have also helped me to understand the nature of sound as a pressure wave. Using tables and graphs, I have succesfully proved my hypothesis. In my extended essay, details have been given on the conclusion and evaluation of the experiment. Possible error sources and solutions to overcome these problems have been mentioned too.

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Introduction

As common sense would help you to understand, sound generates some kind of a pressure. That can be understood by the example of a loudspeaker. When the frequency of the given sound changes suddenly and when it is very high as a value of the frequency, the membrane of the loudspeakers would move outwards. This phenomenon happens mainly due to the sudden frequency change on the sound waves. Despite many people can observe such an event in their daily life, they may not know the reason of it.

There are many interesting experiments that have been done years ago. Some of them are not known if there is not a special reason for them to be investigated. Such an experience has lead me to investigate the Ruben's Tube which I came across to a demonstration of in the internet by chance. Watching the demonstration was not as much satisfactory for me as other people so I decided to experiment it by myself.

Ruben's Tube is quite alike to a loudspeaker when both are observed on the effect of frequency change. On both of them frequency change effects the wavelength of the sound wave. Further examining the Ruben's Tube gave me the idea of investigating effect of sound waves on standing waves. To narrow it a little bit more, I decided to analyse the relation between frequency and wavelength. By determining the relation between those two properties of a sound wave, I will also prove that the sound wave is a pressure wave too.

A Brief Information about Ruben's Tube

Ruben's Tube is a flame tube that demonstrates standing waves. The purpose of the Ruben's Tube is to experiment the relationship between the air pressure and sound waves. Simply, the tube is a long pipe sealed at both ends. Top of the pipe is perforated so that the air can escape. One end of the pipe is attached to a speaker and the other side is attached to a gas supplier. The gas is given into the pipe and the perforations are lit so that the gas leaking from the perforations would inflame. A standing wave is formed with a constant frequency when the leaking gas from perforations is lit. If the speaker is turned on, nodes and antinodes are formed in the tube, therefore if there is high pressure due to sound waves then the flames are higher on the points where more gas try to escape. Also when the sound waves create low pressure, on those points flames are lower.

How is Ruben's Tube created?

In 1904 Heinrich Rubens takes a 4 metre long tube and with 2 centimeter intervals he drilles 200 small holes on the surface of the tube. Then he fills it with a flammable gas. When he lights the gas he realizes the rose of equal heighted flames escaping from the holes. After several trials he comes to the conclusion that when a sound is produced at the end of the tube, it creates a standing wave which is equivalent to the wavelength of the sound given into the tube. Ruben is influenced by the demonstration of an standing wave by placing cork dust in a tube which was experimented by August Kundt in 1866. In this experiment when a sound was made in the tube, the dust lined up as nodes and antinodes with the fluctuation of the sound wave in order to create a standing wave. Also after Kundt, Behn claimed that small flames would be used as the indicators of pressure.

Experiment Design

The aim of this experiment is to prove that sound is a pressure wave and to find out the relationship between the frequency and the wavelength of standing waves which can be observed through a tube whose one end is closed and the other end is attached to a frequency generator via loudspeaker. The tube used for the experiment is called Ruben's Tube.

Before arriving at the final design of the experiment, I have planned to use an music device instead of a frequency generator. My intention was to plug in the music into the loudspeaker and observe the motion of the waves however after further revision of this method, I realised that would be difficult to collect accurate data because the waves would be in motion and the frequency given by the music would change contuniously. Although taking momentary pictures would have helped me to investigate the amplitudes of the antinodes and the wavelengths, it would still be risky and difficult because of frequently changing frequency of the music.

A better approach is developed after further research about Ruben's Tube. Instead of pluging in a music device to the loudspeakers, attaching a frequency generator to the loudspeakers decided to be more logical in order to get more accurate data. For the new experiment design, using Audacity® which is a software for recording and editing sounds is found appropriate.

A revised hypothesis with a modified experiment design is done after new approach for the experiment. Since sound waves are characterized as longitudinal waves therefore according to the new design of the experiment longitudinal waves would be formed in the tube however it would be observed as a standing wave with the help of fire. High and low pressure regions would be created in the tube according to the frequency of the wave generator. The sine waveform is going to be given as the tone and the amplitude will be kept constant. According to my expectations since a tube can resonate, then a standing wave can be set up within it. Therefore, the flames would be higher on the higher frequencies.

Background Information

Characteristic of the sound waves comes from the back and forth vibration of the particles of the medium through which the sound wave is moving. If a sound wave is moving from left to right through air, then particles of air will be displaced both rightward and leftward as the energy of the sound wave passes through it. This is what makes sound wave a longitudinal wave.

Air particles make longitudinal motion therefore two kinds of regions are created according to the compression of particles as compressed together or as spreaded apart. When there is high air pressure on a region than it is called compression however when there is a medium of low air pressure than it is called rarefaction. A sound wave is formed of high and low pressure regions therefore it is referred as a pressure wave. The fluctuations in pressure as detected by a detector occur at periodic and regular time intervals. In fact, a plot of pressure versus time would appear as a sine curve. The peak points of the sine curve correspond to compressions; the low points correspond to rarefactions; and the "zero points" correspond to the pressure which the air would have if there were no disturbance moving through it.

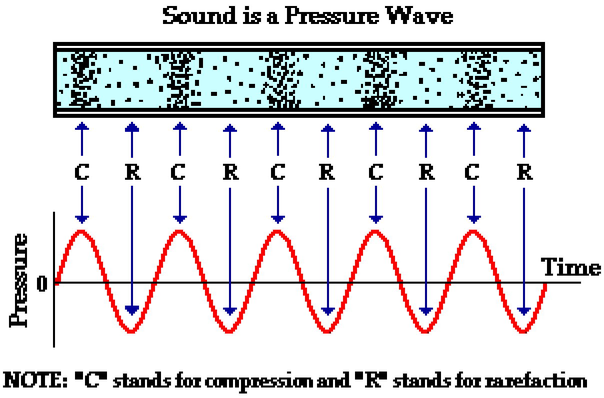


Figure 1: Sound is a pressure wave of sine curve.[1]

Standing waves produced in Ruben's tube are open at one end and closed on the other therefore the wave will start with a node and end with an antinode. The reason of such behaviour of the wave is the air pressure oscillation at the closed end since it has the greatest amplitude and forms an antinode.

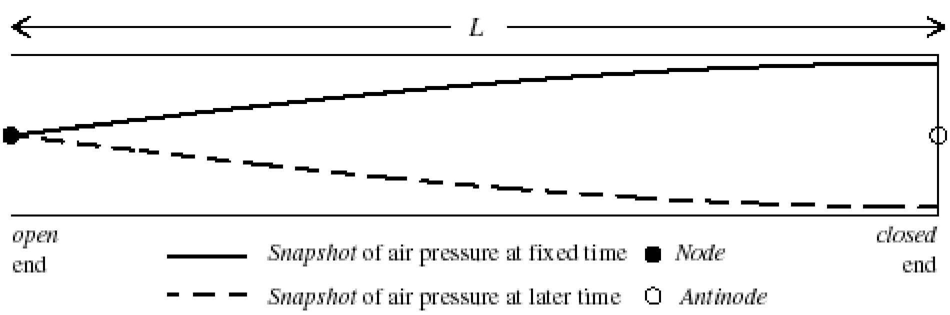


Figure 2: Standing sound wave in a pipe with an open and closed end.[2]

[1] Figure taken from the website: www.glenbrook.k12.il.us
[2] Figure taken from the webdocument: http://hep.physics.indiana.edu/~rickv/Standing_Sound_Waves.html

Experimental Procedure

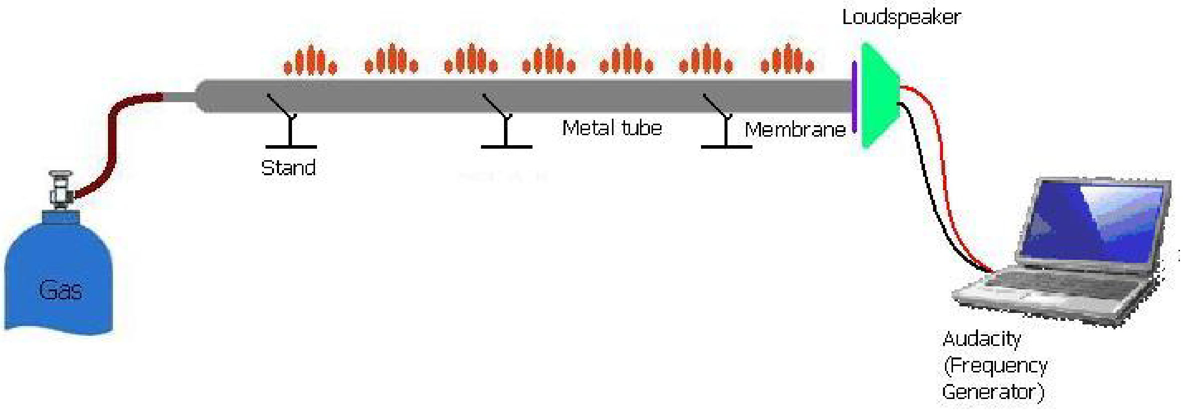


Figure 3: Setup of the experiment.

List of Apparatus

- Gas burner
- Metal tube open in both ends
- Loudspeaker
- Frequency generator (Audacity)
- Rubber membrane
- Metal lid as with the same radius of tube or rubber stopper
- Lighter
- 3 stands
- Digital thermometer

In this investigation a cylindrical metal tube of length 2 meters and with a radius of 5 centimeters is obtained. At the beginning of the experiment both ends of the tube are kept open. An important point is using a tube made up of aluminium or steel because a tube made up of copper would be dangerous since copper conducts heat which may melt the rubber membrane that will be located to one end of the tube. In this investigation an aluminium tube is used. 10 centimeter part of the cylindrical tube from two end are not drilled to open the holes. Diameter of circular holes is 2 mm. Seperations between the circular holes are equal On this stage of the experimental setup, it is important to drill the holes closely and on the same line so they will be approximately 15 centimeters apart from each other. One of the ends is closed with a rubber membrane making sure there is not any openings on the membrane that would result in escape of gas from the covered end of the tube. A rubber stopper, that just fits the open end, is installed to the other end of tube. Before the attachment, a hole is made on the rubber stopper big enough so that the tip of the gas burner's pipe would fit in just as tight. After installation of rubber stopper and membrane the tube is placed on the three stands.

The system is checked in case of any leak of gas which might be dangerous for the duration of the experiment. In order to do that the gas burner's pipe and the proper end of the tube which has a hole are attached together. Other end of the tube which is covered with the rubber membrane is controlled too. At that point setup of the experiment is complete. The gas is turned on and after 15 seconds, top of the tube which is perforated is lighted. The reason of waiting for 15 seconds is to let the gas fill in the tube and spread out in the tube. After lighting the tube every opening gets flame as the gas escapes through the openings. For the first trial all of the openings did not get flame so the openings are lighted again. After making sure there is not any leak of gas from anywhere of the tube except the top, gas is turned off. Another important point is that the tube must be airtight. If not, the gas might escape from elsewhere than the openings and all setup might catch fire. The loudspeaker is put as close as to the end with the rubber membrane of the tube. It is connected to a frequency generator. For this experiment Audacity® is used as a frequency generator. At that time setup is similar to figure 1. The gas is turned on and the openings are lighted again. Making several calculations for the appropriate frequency, estimated resonant frequencies are generated on the Audacity. The frequency is varied in order to produce perfectly shaped standing waves. The pressure of the gas is adjusted to produce better standing waves.

For each different frequency, room temperature is measured which helps to calculate the speed of sound. After the collection of the data and trying all the estimated frequencies, unestimated frequencies are tried too. The above steps are repeated for each frequency. The experiment is continued until a spectrum of data has been collected.

Figure 4: Photo taken before the final setup of the experiment.

Controlling of Variables

Different conditions would have different effects on the experiment. Independent variable for this experiment is only the frequency. In a direct relation with the independent variable, dependent variable is the effect of the frequency on the standing waves generated. The following variables must be controlled to investigate the effect of the frequency change on the standing waves.

1. Room Temperature

The speed of sound depends on temperature. It is known that the speed of sound is 340.29 m/s at sea level however the experiement is held in a school labaratory therefore temperature has an impact on the calculations. It is found by the following formula:

$$V = (331.5 \pm 1.0\, m/s) + (0.6 \pm 0.1 m/s°C) \times T_c$$ [3]

Although room temperature is tried to be kept constant in the experiment since the fire is used there might have been slightly differences so in order to overcome this problem temperature is controlled before each trial and calculations are revised. Also humidity is an important factor for determining the speed of sound however conditions in the labaratory is not complete in every respect to take the humudity in consideration. A further analysis about the unknown humidity will be presented in the evaluation.

2. Length of the Tube

Standing waves can occur in any wave medium that is enclosed, including the air. In order to obtain the best value for the frequency generated there are some calculations made. Wavelength and the length of the tube is directly proportinal so the wavelength of the wave produced is determined by the below equation:

$$\lambda = 4L/n$$

λ = wavelength
L = length of the tube
n = 1, 3, 5, …

As the equation above clarifies, the length of the tube changes the wavelength therefore changes the necessarily generated frequency values too. In the experiment a 2 meters long tube is used however 10 centimeter long spaces are not drilled in case of gas leak on the membranes and as a precaution for the rubber membrane not to melt. So the length of the will be taken as 1.80 meters because of the 10 centimeter long undrilled spaces on both sides.

[3] Formula taken from the webdocument: http://newterra.chemeketa.edu/faculty/ejensen/docs/standingsoundonline.doc

3. Gas Pressure

Another controlled variable is the gas pressure. Natural gas is used in the experiment. It does not have a direct effect on the calculation of the data however collection of the data is mainly based on the gas pressure.

Experiment is done in a laboratory without any current of air. Air conditionings and windows are closed so the standing waves would be produced successfully. At the beginning of the experiment, some of the trials have failed because straight up standing waves were not produced. After adapting the gas pressure, standing waves are successfully produced. In the experiment, we accept the assumption that the same gas pressure would work for each frequency and we did not change the pressure and did not make trials for the best gas pressure for different frequencies. The gas pressure is indirectly controlled and also it can be considered as a dependent variable however it is a semi-controlled variable for this experiment. When the gas pressure in the tube is considered, then it is a dependent variable because as the frequency changes, the escape of the gas changes too which we observe as higher flames.

4. Determination of the Number of Antinodes & Nodes

Frequency and the number of antinodes and nodes are directly proportional. As the frequency generated is increased the wavelength of the wave decreases therefore the number of antinodes and nodes increases because more standing waves are produced. Wavelength is found by the formula:

$$\lambda = 4L/n$$

in which n is one less than the total number of antinodes and nodes. Since the tube is considered one end open, then the number of nodes and antinodes are equal. The wave starts with a node and ends with an antinode. The wavelength and the frequency are related by the equation of speed of sound.

$$f = V/\lambda$$

f = frequency
V = speed of sound
λ = wavelength

In the given equation above, wavelength and frequency are inversely proportional on the other hand frequency of wave generator and the number of nodes and antinodes are directly proportional. During the experiment even if the number of antinodes and nodes could be determined by calculations, it can be observed too. If the number of antinodes are not as much as the expected value than the calculations are revised and trial is repeated. This is a good source of recognizing the errors in the calculations because of the differences between the expected number and the observed number.

Data Collected and Calculated

- Room Temperature: 20.1 ±0.1 °C
- Speed of sound: 343.2 ± 0.1 m/s
- Tube's length: 1.80±0.01 meters

Table 1

Number of nodes+antinodes	1+1	2+2	3+3	4+4
Wavelength (m)	7.20	2.40	1.44	1.03
Estimated (actual) frequency (Hz)	47.7	143.0	239.0	334.0
Generated frequency for the best standing waves (Hz)	45.4	137.0	228.0	318.0
Percentage Error (%)	4.19	4.20	4.60	4.79
Average Percentage Error (%)	3.41			

Table1: Calculated and actual datas for the experiment. (Continued in the appendix)

* On the table, there is only one generated frequency for each wavelength because there is only one value of frequency generated for the best standing waves. Many other trials have been made to obtain the best standing wave.

Calculation of Data

$$V = (331.5 \pm 1.0\, m/s) + (0.6 \pm 0.1 m/s°C) \text{ x } T_c$$

T_c = temperature in °C

f = V / λ V = speed of sound
λ = wavelength
f = frequency

λ = 4L/n
L = length of air in tube
n = 1, 3, 5,…
n = number of total antinodes and nodes – 1

Percentage Error

$$\text{Percentage Error} = \frac{|\text{Measured-Actual}|}{\text{Actual}} \text{x}100$$

Average Percentage Error

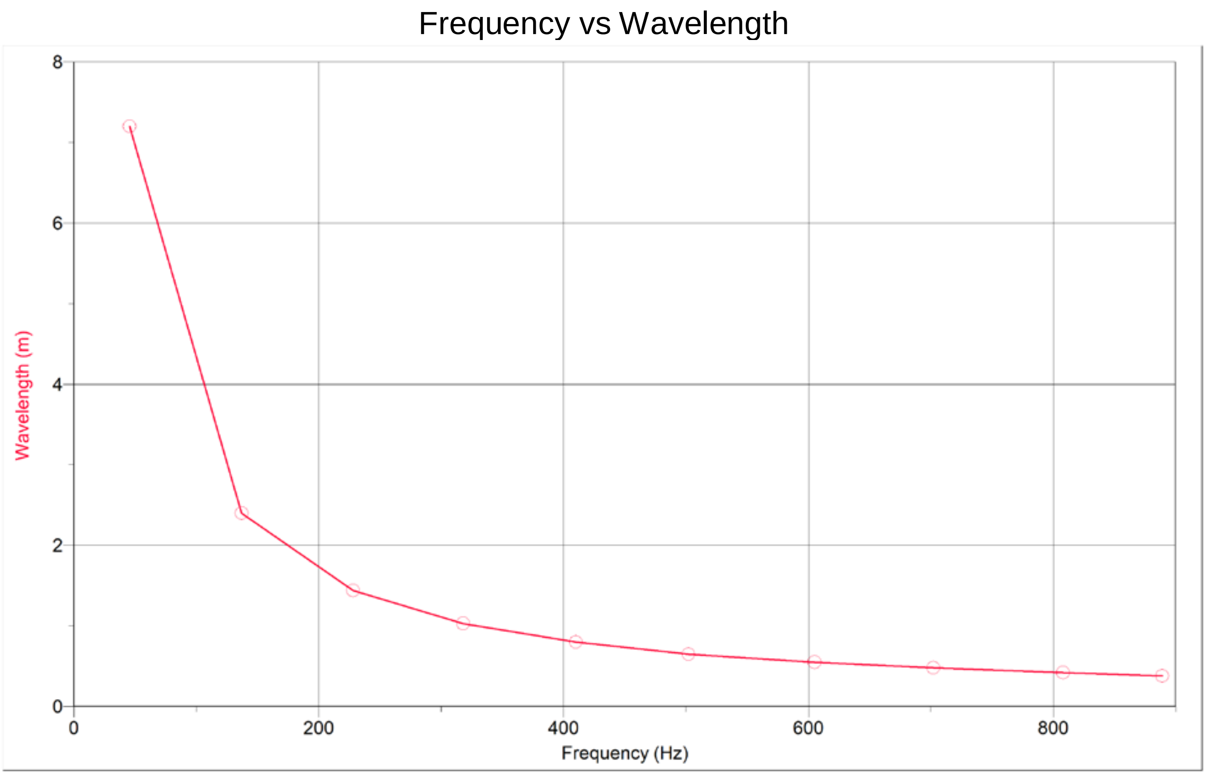
Average Percentage Error= Sum of Percentage Errors / Number of Trials

Analysis of Data

As seen from the data collected on the previous pages, the generated frequencies have an average error of 3.41% which is calculated by the comparison of calculated data and the best frequency that I observed for the best standing waves to be produced during the experiment.

After inputting the tabulated data into Logger Pro which is a spreadsheet program, a graph is obtained such that:

Graph 1



Graph 1: Frequency vs wavelength graph according to the data given in Table 1.

According to the wavelength versus frequency graph a gradually decreasing graph is obtained which shows the inverse proportion between wavelength and the frequency for a wave obtained. While the wavelength decreases, the frequency increases according to the graph. Since wavelength and the number of nodes and antinodes are inversely proportional, then it can be concluded that the number of nodes and antinodes are directly proportional with the frequency.

Conclusion

As verified from the graph, the wavelength and the frequency generated and given into the tube are inversely proportional. This completely matched my hypothesis since the change in frequency has affected the wavelength too.

$$f = V / \lambda$$
$$\lambda = 4L/n$$

As the actual values calculated by the given formulas, the overall formula is found to be **f = Vn/ 4L**. Since the experiment setup is based on Ruben's tube, it is considered as a closed tube on both ends. In a one end closed tube sound wave starts with a node and ends with an antinode therefore in the formula n is one less than the total number of nodes and antinodes in the wave. Speed of sound is calculated in order to find the V value. L value has been the length of pipe in meters however the unholed parts of the tube is substracted from the total length because on those parts there would not escape any air therefore gas would not escape.

My another hypothesis was that sound is a pressure wave. I have succesfully proved this. In the experiment it has been observed that pressure regions cause the gas to be pushed out with a least force at a node than at an antinode. Also when the frequency generated is increased, the change in the height of the flames has been successfully observed. As the frequency increasedi the height of flames increase too which is another proof of sound as a pressure wave because as the frequency increases the gas particles are pressed together with a greater force therefore the flames heighten up. Demonstration of Ruben's Tube reveals a flame pattern that is transverse in nature. My experiment has demonstrated the same pattern too. Since the sound waves in different frequencies are controlling the harmony of the flames, the amplitude of the wave formed has changed throughout the experiment as the frequency values changed too. During the experiment it is observed as, the standing wave has a node so that the flames are small. When the gas pressure is constant, a high sound frequency from the speaker creates high flames at the nodes and a low sound frequency creates low flames at the nodes. Also when the sound intensity is constant, the flames are highest at the antinodes of the standing wave. As a result of those, when the gas pressure is low and the sound pressure is high, atmospheric pressure can be sucked into the tube. By the help of these observations, it can be concluded that sound is a pressure wave as well as a longitudinal wave.

Evaluation

The results obtained in the experiment are quite accurate with an average percentage error of 3.41% however on the graph a direct line could not be obtained therefore best fit line is drawn. The actual points on the graph deviate from the best fit line on some points. There are some errors in the experiment which has caused the percentage error of 3.41%. Those errors would be:

- The formula that is used to determine the speed of sound in room temperature may have quite failed because of the non adjustment of the effect of unknown humidity since it has taken into consideration. In order to overcome this problem another formula would have been used that the humidity is added into calculation too however the experiment needs to be held in a lab that has hygrometer.

- Temperature change in the lab may have affected the results. Fire has been used to observed the standing waves. As a result of using fire, the room temperature has rised a little after a while. On the design stage of the experiment, about temperature, it has been planned as to be checked after each trial so temperature is checked however a significant change has not been observed on the thermometer. In order to not to have such an error source, more sensitive thermometers should be obtained and checked regularly before each trial and calculations should be made accurately, based on the temperature change.

- Expansion may have occurred on the tube because it has been heated for a long time however this would have been a slightly source of error because of the high expansion heat of the metarial used for the tube. To overcome such a probable source of error, after each trial tube could have been cooled down however this is not an easy thing to do so this source of error could be neglected.

- Another source of error would have been because of the calculations. Length of the tube has been taken as 1.80 meters however the actual length of the tube is 2.00 meters. It has been taken as 1.80 meters because of the fact that there was some unholed places at the both ends in order to prevent any incident of catching fire of any material used. The generated frequency values for the best standing waves are closely to the calculated values of the given formulas when the L is taken as 2.00 meters. Therefore I conclude that L value should have been taken as 2.00. This is the main human originated error of the experiment since it has affected the calculated values too. For such an experiment, length of the pipe should be taken directly into calculations.

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Appendix

Continued from the table on page 11

Number of nodes+antinodes	5+5	6+6	7+7	8+8
Wavelength (m)	0.80	0.65	0.55	0.48
Estimated (actual) frequency (Hz)	429.0	525.0	624.0	715.0
Generated frequency for the best standing waves (Hz)	410.0	502.0	605.0	702.0
Percentage Error (%)	4.43	4.38	3.04	1.82
Average Percentage Error (%)	3.41			

Number of nodes+antinodes	9+9	10+10
Wavelength (m)	0.42	0.38
Estimated (actual) frequency (Hz)	817.1	903.2
Generated frequency for the best standing waves (Hz)	808.0	889.0
Percentage Error (%)	1.10	1.57
Average Percentage Error (%)	3.41	

Table1: Calculated and actual datas for the experiment.