PHYSICS EXTENDED ESSAY

Topic: Investigation of The Relationship Between Sound Pressure Level and Water Height

Word Count:3559

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1.Introduction:

Sound acts differently depending on the environment it goes through. Small changes in the shape or size of the environment can lead to identifiable changes in sound intensity. When sound is produced near an object it spreads, becoming louder or quieter. As shape is an indicator that affects sound waves, it determines the sound level measured by an individual or device. One example is that a graduated cylinder as it acts as a narrow vertical shape for sound waves to travel. In this essay, sound levels are measured and used in decibels rather than pascals even though pressure’s unit is Pa. Reason for this is because auditory waves’ pressure values are extremely small. For this reason direct comparison between certain measurements is difficult. Using the decibel scale helps to express sound pressure level in a certain reference value more clearly as it uses a logarithmic relationship to express such values. To add more, human auditory system measures the changes in the sound pressure logartihmically. This means that equal increases in physical pressure does not represent the perceived loudness. Therefore, using the sound pressure levels as dB helps create a more practical and meaningful analysis in terms of sound in the air column.

2.Background Information:

Most of the mechanical waves require a medium to travel, such as sound. Some of the examples of the mediums are water and air. Sound is produced when an object vibrates which causes the particles around the medium to oscillate back and forth. These vibration transfer energy from one particle to another which,at the end, creates sound.

2.1 Longitudinal Waves:

Sound waves are longitudinal waves which means that the particles of the medium vibrates at the same direction in which the waves travel. As sound moves through, it creates areas where particles are pushed close and where particles are pushed apart. They are called compressions and rarefactions respectively. These two concepts carries the sound energy.

2.2 Sound Intensity:

Sound intensity is the measure that how much sound energy passes through an area per second. Higher sound intensity means that more energy is being transferred by the wave created by the sound. Therefore, louder sounds tend to have higher sound intensities and quieter sounds tend to have lower.

2.3 Decibel Scale:

Decibel scale is used to measure sound levels. As humans can not detect the sound intensity produced by a source, while using decibel scale one can detect the decibel (dB) that the source produced. Decibel scale uses a logarithmic scale for measuring the level of the sound. The formula for calculating sound level is given by;

$$L = 10\log\frac{I}{I_0}$$

Where;
- I is the sound intensity
- I_0 which equals to 1 x 10^{-12} W/m^2 is the reference intensity.

This equation allows to measure both very quiet and very loud sounds produced by a source.

2.4 Wave Reflection:

Wave reflection occurs when a part of the wave is reflected because of the sound wave reaches a boundary between two different mediums. Main reason for a wave to reflect is that a sound wave cannot entirely pass into a new medium. One example is that water flow, as water has a higher acoustic impedance than air, it will reflect the sound waves, therefore act as a boundary.

2.5 Interference Of Sound Waves:

Sound waves overlap with incoming waves when reflected. This is called interference. If the waves meet in phase, it is called constructive interference which increases sound intensity. If the waves meet out of the phase, it is called destructive interference which decreases sound intensity.

2.6 Sound Intensity and Amplitude:

Sound intensity and Amplitude are two concepts that related to each other and sound intensity is directly related to the square of a particular wave's amplitude. Larger amplitude results in larger pressure in the air. As a result, this results in higher sound intensity.

2.7 Air Column and Boundary Conditions:

Air column is a term that is represented in two groups: open and closed respectively. Indicating whether an air column is open or closed depends on its boundary conditions. While closed end represents a displacement node, open end represents a displacement antinode.

In this experiment, the graduated cylinder's water surface is considered as a closed end and the top acts as an open end. This represents that system is a closed-open column. In general, closed-open air columns support varied resonance lengths.

Calculating a closed-open air column is given by the formula:

$$L = \frac{\lambda}{4}$$

Where λ is the wavelength of the sound produced.

The length of the air column above the graduated cylinder changes as there is an increase of decrease in the water level. Because sound propagates through air, the air column length is considered one of the key factors that affects resonance levels. When water levels increase, air column will become shorter and when water level falls, air column will be longer.

3.Variables:

Independent Variable: Height of the water in the graduated cylinder (0-10,10-20,20-30,30-40,40-50,50-60,60-70,70-80,80-90,90-100 cm) in this experiment.

Dependent Variable: Sound Pressure Level in decibels (dB). Sound intensity will change when the height of the water in the graduated cylinder increases. As a result Sound Pressure Level (SPL) will change.

Controlled Variables	*Why is it Controlled?*	*How is it Controlled?*
Distance between sound source and cylinder	*Sound intensity changes when difference change so changing the distance may change the results.*	*The sound source was placed at a fixed position relative to the top of the graduated cylinder and kept constant throughout the experiment.*
Frequency of the sound source	*As sound resonance depends on frequency, using a fixed frequency of the sound source can increase the reliability of the results.*	*Throughout the experiment the same source which produces a constant frequency were used.*
Type of the graduated cylinder	*Different materials react to sound differently so using the same graduated cylinder throughout the experiment increases the reliability and accuracy of the results.*	*The same graduated cylinder is used throughout the experiment.*
Background noise	*As additional external noises can result in a change in the SPL, experimenting in an isolated room can increase the accuracy of the results.*	*All of the experiment is done in the same room. Room is kept quiet until the experiment finished and doors and windows were shut to prevent external noises.*
Room Temprature	*Speed of sound waves depends on temperature so maintaining the same temperature for throughout the experiment is necessary.*	*All measurements were taken in the same room to ensure that the temperature was the same.*

Table 1. Controlled Variable Table, Why is it Controlled and How is it Controlled.

4.Methodology

4.1 Material List

- Graduated Cylinder (0-100 ± 0.5cm^3)
- Water Source
- Smartphone
- Frequency Measuring Application
- Quiet Room
- Pen
- Camera
-Paper

4.2 Experimentation Setup

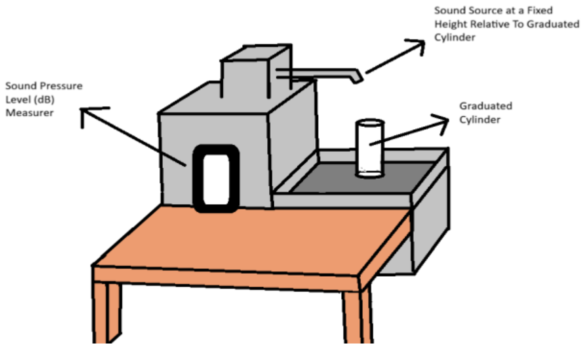

Figure 1. Experimentation Setup Model

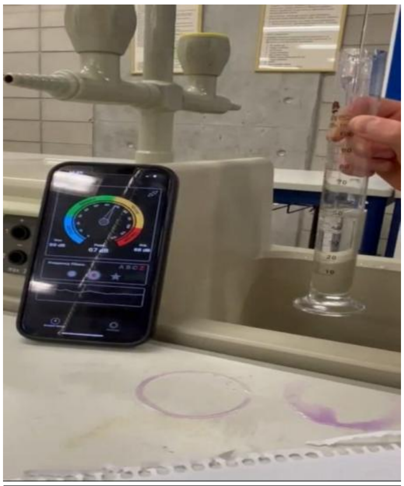

Figure 2. Experimentation Setup Picture

4.3 Procedure

1. Place the graduated cylinder (0-100 cm^3) under the constant frequency water source.

2. Open the frequency measure application from the smartphone.

3. Mark the intervals that you are working on the graduated cylinder.

4. Place the camera where it can see both the graduated cylinder and smartphone.

5. Start the camera recording.

6. Open the water source and leave it open during the experiment for accuracy.

7. When the graduated cylinder is full, close the camera recording.

8. Identify the frequency of the sound by stopping the recorded mix-tape for every interval.

9. Write down the datas that you collected with the help of pen and paper.

10. Pour the water that is in the graduated cylinder to a sink.

11. Open the new recording.

12. Put the graduated cylinder at the same position.

13. Repeat steps 1-12 4 times to increase the reliability of the results.

5.Safety Tips

1. Water may spill during the experiment. For this reason, wipe the spilled water in order to prevent harm for the electronic devices.
2. Keep the electronic devices distant from the sound source. As the water source may result in electrical damage to the devices and to the environment.
3. Conduct the experiment in an isolated and quiet area in order to prevent distractions caused by the noise.

5.Ethical Considerations

1. In this investigation, neither a human nor an animal is participated. For this reason no ethical consent needed.
2. All of the contained data were recorded and processed with honesty. No alterations or processing present in the datas.
3. Limitations and Strengths were analyzed and reported to prevent misleading in the conclusion.

5.Enviornmental Considerations

1. Experiment only contained water. It did not contained any hazardous materials. For this reason, environmental pollution is prevented.

2. Electronic devices operated only when necessary. This minimized the energy consumption of these devices.

6.Calculations

To further investigate the effect of water height on sound pressure level (SPL), several calculations were made with the use of raw data table. Raw data table helped to obtain certain measurements for further analysis such as Mean Sound Pressure Level, Uncertainty, Logarithmic Decibel Scale and Air Column Length.

Raw Data Table

Water Height (±0.5)(cm)	*Sound Pressure Levels in Trial 1 (dB) ±1.0*	*Sound Pressure Levels in Trial 2 (dB) ±1.0*	*Sound Pressure Levels in Trial 3 (dB) ±1.0*	*Sound Pressure Levels in Trial 4 (dB) ±1.0*
0-10.0	*71.0*	*69.0*	*68.0*	*61.0*
10.0-20.0	*77.0*	*65.0*	*60.0*	*64.0*
20.0-30.0	*80.0*	*66.0*	*64.0*	*65.0*
30.0-40.0	*73.0*	*67.0*	*74.0*	*68.0*
40.0-50.0	*72.0*	*75.0*	*67.0*	*65.0*
50.0-60.0	*70.0*	*70.0*	*66.0*	*65.0.*
60.0-70.0	*77.0*	*73.0*	*72.0*	*69.0*
70.0-80.0	*82.0*	*80.0*	*71.0*	*73.0*
80.0-90.0	*72.0*	*75.0*	*71.0*	*70.0*
90.0-100.0	*75.0*	*70.0*	*73.0*	*69.0*

Table 2. Complete Raw Data Table Containing Water Height Intervals and Values of Sound Pressure Level in Each Trial

The table shows each sound pressure level value (dB) for the intervals given. Because the sound pressure level values were calculated by frequency measuring application, uncertainty for dB values cannot be calculated. For this reason, in this experiment, the uncertainty values for sound pressure level values were taken as ±*1.0.*

First calculation in the experiment is the mean sound pressure level is measured for each interval which is calculated by the formula:

$$\frac{L + L_1 + L_2 + L_3 + L_4}{4} = L_M$$

Where L_1,L_2,L_3,L_4 are SPL readings and L_M is the mean sound pressure level.

Sample Calculation

While calculating the mean sound pressure level (0-10.0 cm) water height will be used as sample calculations. For this reason the SPL values are;

$L_1=71\ dB$
$L_2=69\ dB$
$L_3=68\ dB$
$L_4=61\ dB$

Now applying the formula for this interval:

$$\frac{71+69+68+61}{4}=L_M$$

L_M=67.25 dB. This value shows the mean sound pressure level for the interval (0-10 cm).

Sample Calculation

Now the same interval will be used to calculate the uncertainty for the Mean SPL

$$\delta L_{mean}=\frac{L_{max}-L_{min}}{2}$$

This is the formula to calculate the uncertainty values for Mean SPL values. Now applying the values in the interval (0-10.0 cm) water height;

$$\frac{71-61}{2}=\delta L$$

$$\delta L=\pm 5.0\ dB$$

This sample calculation shows that the uncertainty for the sample interval is ±5.0 dB.

Now applying the formula for the whole data table the processed data table for mean sound pressure level is created.

Water height (cm)(±0.5)	*Mean SPL (dB)*	*Uncertainty (δ) (±dB)*
0-10	*67.25*	*5.0*
10-20	*66.50*	*8.5*
20-30	*68.75*	*8.0*
30-40	*70.50*	*3.5*

40-50	*69.25*	*5.0*
50-60	*67.75*	*2.5*
60-70	*72.75*	*4.0*
70-80	*76.50*	*5.5*
80-90	*72.00*	*2.5*
90-100	*71.75*	*3.0*

Table 3. Proccessed Data Table For Mean Sound Pressure Level

Secondly, as the decibel scale is given by a logarithmic formula one can calculate the ratio between the measured sound intensity and reference intensity. Because it cannot measure absolute intensity itself this formula can only show the ratio between them. The formula for the logarithmic scale is:

$$L = 10 \log \frac{I}{I_0}$$

Where I is the measured intensity and I_0 is the reference intensity. Reference intensity refers to the lowest mean sound pressure level recorded.

Sample Calculation

Again using (0-10.0) interval for the sample, sample calculations can be made for measuring the intensity ratio.

Because we use (0-10.0) as sample, L_{ref} and measured SPL values can be directly deduced from the table where:

- L_{ref} :66.50 dB
- L= 67.25 dB

With the given values, the intensity ratio formula can be derived to make the calculations which is:

$$I_r = log^{\frac{\Delta L}{10}}$$

Where ΔL is the change in the mean SPL values.

Calculation

Step-1

- L_{ref} :66.50 dB
- L= 67.25 dB

ΔL= 67.25 - 66.50

ΔL=0.75 dB

Step-2

$$I_r = log^{\frac{0.75}{10}}$$

$$I_r = 10^{0.0075} \approx 1.19$$

This sample calculation shows that the sound intensity at the water interval (0-10.0 cm) is approximately 1.19 times bigger than the reference intensity. As the intensity ratio is a derived formula from the logarithmic scale, uncertainties for intensity ratio values will not be calculated.

Now applying the formula for the whole data set, calculations for other intervals can be made which is given in the table:

Water Height (cm)	Mean SPL (dB)	ΔL (dB)	Intensity Ratio
0-10	67.25	0.75	1.19
10-20	66.50	0.00	1.00
20-30	68.75	2.25	1.68
30-40	70.50	4.00	2.51
40-50	69.75	3.25	2.11
50-60	67.75	1.25	1.33
60-70	72.75	6.25	4.22
70-80	76.50	10.00	10.00
80-90	72.00	5.50	3.55
90-100	71.75	5.25	3.35

Table 4. Processed Data Table Showing The Change in SPL Values and Intensity Ratios.

Last but not least, one of the calculations will be done in this investigation is going to be the air column length. Calculating the air column length allows that the experiment to further analyzed through air conditions which is related to resonance. In the experiment the total height of the graduated cylinder is 100 cm. For this reason, The space in the air column above the surface is shown by the formula:

$$L_{air} = 100 - h_{water}$$

Using the formula with the sample interval which is (0-10 cm), air column length calculation can be made where:

H= 100 cm and approximate water height h= 5 cm

Applying these values to the formula:

$$L_{air} = 100 - 5 = 95\ cm$$

This value gives us the space above the water in the cylinder which directly influences sound pressure level (SPL) itself.

Now applying the formula to the all of the intervals in the raw data table a new processed table for air column length can be made.

Water Height (cm)	Approximate Water Height (cm)	Air Column Length (cm)
0-10.0	5.0	95.0
10.0-20.0	15.0	85.0
20.0-30.0	25.0	75.0
30.0-40.0	35.0	65.0
40.0-50.0	45.0	55.0
50.0-60.0	55.0	45.0
60.0-70.0	65.0	35.0
70.0-80.0	75.0	25.0
80.0-90.0	85.0	15.0
90.0-100.0	95.0	5.0

Table 5. Processed Data Table Showing Approximate Water Height in cm and Air Column Length in cm.

The last calculation that is going to be made is the Error Propagation and Percentage Error for Intensity Ratios. Error Propagation is used to find out how uncertainties in sound pressure levels for each interval affected intensity ratios. However, calculating only the absolute uncertainty does not clearly represent the relativity for the calculated intensity ratios. Because of this, percentage error for each interval is calculated. This way, propagated intensity can be represented as a fraction of the intensity ratio itself. This not only increases the reliability of the experiment but also helps represent a more clear comparison between each interval. The formula for calculating the error propagation is given by;

$$\frac{dI_r}{d\Delta L} = \frac{\ln 10}{10} * 10^{\Delta L/10}$$

$$\frac{\ln 10}{10} = 0.230$$

$$\delta I_r = 0.230 I_r * \delta \Delta L$$

This formula gives the uncertainties for the intensity ratios which is used to calculate the percentage error. Where percentage error is calculated by;

$$Percentage\ Error = \frac{\delta I_r}{I_r}\ x\ 100 = 23\delta(\Delta L)$$

Sample Calculation

I_r=*1.19*

δI_r=*1.37*

$$\%\ Error = \frac{1.37}{1.19}\ x\ 100$$

$$\%\ Error = 1.151\ x\ 100 = 115\%$$

This calculation shows the percentage error for (0-10.0) interval. Now applying these formulas to the whole dataset the table for percentage error for intensity ratios can be made.

Water Height (cm)(*±0.5*)	Intensity Ratio $\left(\frac{I}{I_0}\right)$	$\delta L(dB)$	Uncertainty in Intensity Ratio $\delta\left(\frac{I}{I_0}\right)$	Percentage Error (%)
0-10.0	1.19	5.0	1.37	115.2
10.0-20.0	1.00	8.5	1.96	196
20.0-30.0	1.68	8.0	3.09	184
30.0-40.0	2.51	3.5	2.02	81
40.0-50.0	2.11	5.0	2.43	115
50.0-60.0	1.33	2.5	0.77	58

60.0-70.0	4.22	4.0	3.89	92
70.0-80.0	10.00	5.5	12.67	127
80.0-90.0	3.55	2.5	2.04	58
90.0-100.0	3.35	3.0	2.31	69

Table 6. Percentage Error Table for Intensity Ratios in each interval with uncertainties

7.Data Analysis

To begin with, as the water height increases the mean sound pressure level decreases. However, the relationship between water height and mean sound pressure level does not show a directly linear relationship. Uncertainty bars shows that at some point data points overlap within experimental uncertainty but the downward trend continues without changing direction. This means that the changes are caused by systematic errors rather than random errors. This problem can be caused by external noises and the quality of the microphone of the phone that is recorded to use sound levels. These can be supported by Figure 2. which shows the relationship between mean sound pressure level and water height.

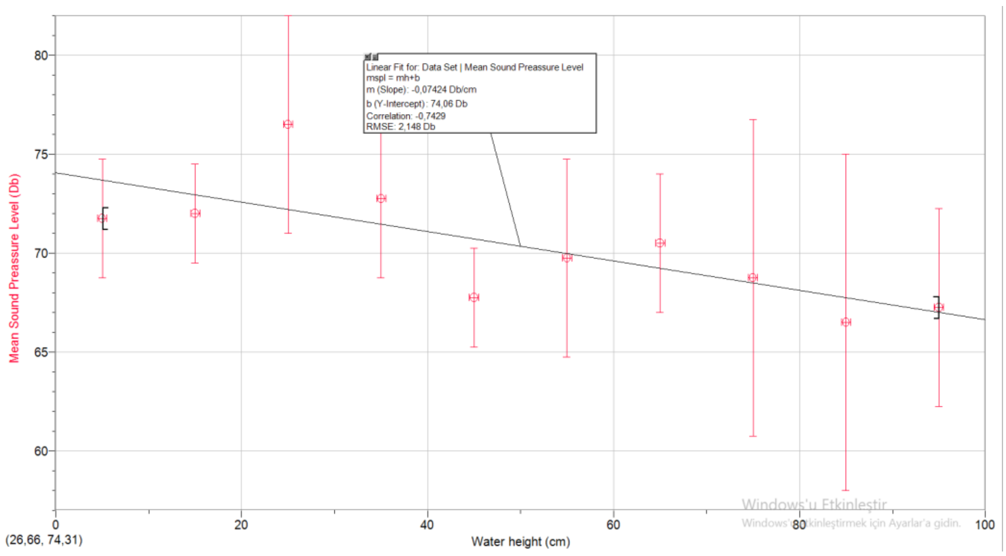

Figure 3. Relationship between sound pressure Level and Water Height

Even though Figure 3. shows the relationship between sound pressure level and water height, this alone does not shows the reason why such changes occur. This is because the formula used to calculate decibel scale is logarithmic. To be exact, equal changes in decibel values does not accurately show equal changes in sound intensity. For this reason, mean sound pressure level datas converted into intensity ratios using reference sound levels for each interval. This not only allows the data to be analyzed in terms of energy transfer, but also increases the reliability of the results.

As a result, the relationship between intensity ratios with water height is plotted as a scatter graph.

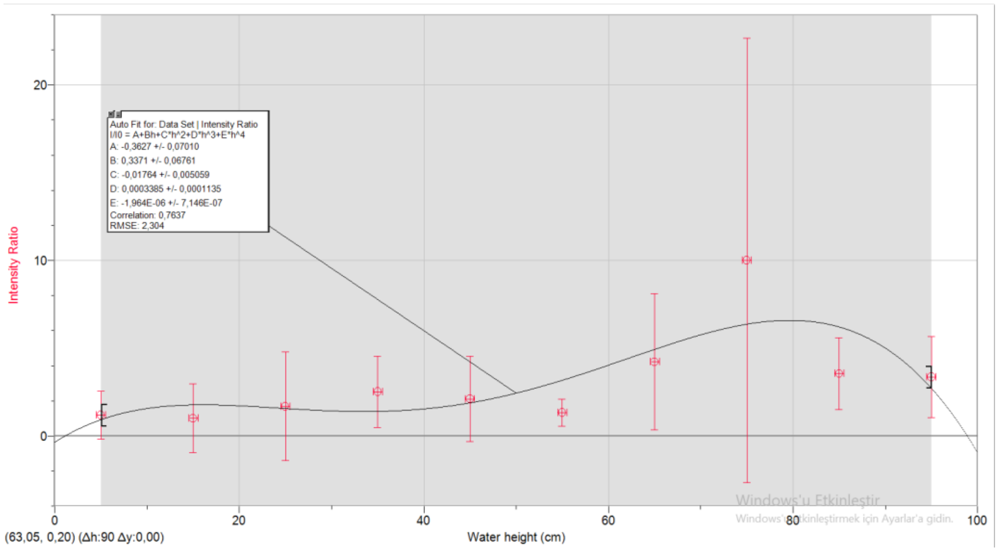

Figure 4. Relationship Between Intensity Ratios and Water Height.

Figure 4. shows a peak intensity in 75 cm in water height. This significant increase in intensity means that there is a strong amplification of sound. However, this point can be considered as escape point. Also, this can be considered as a feature of air column resonance. When resonance happens, incident waves and sound waves interfere which results the wave amplitude to increase and result in a maximum sound intensity. Although there were no other peaks have seen in the taken intervals, high uncertainties may represent that external effects that effect resonance may not be identified. However, the maximum intensity in the graph may be because of the resonance behaviour rather than random errors.

To analyze the concept further, intensity ratios is plotted against air column length. This relationship is shown in Figure 5.

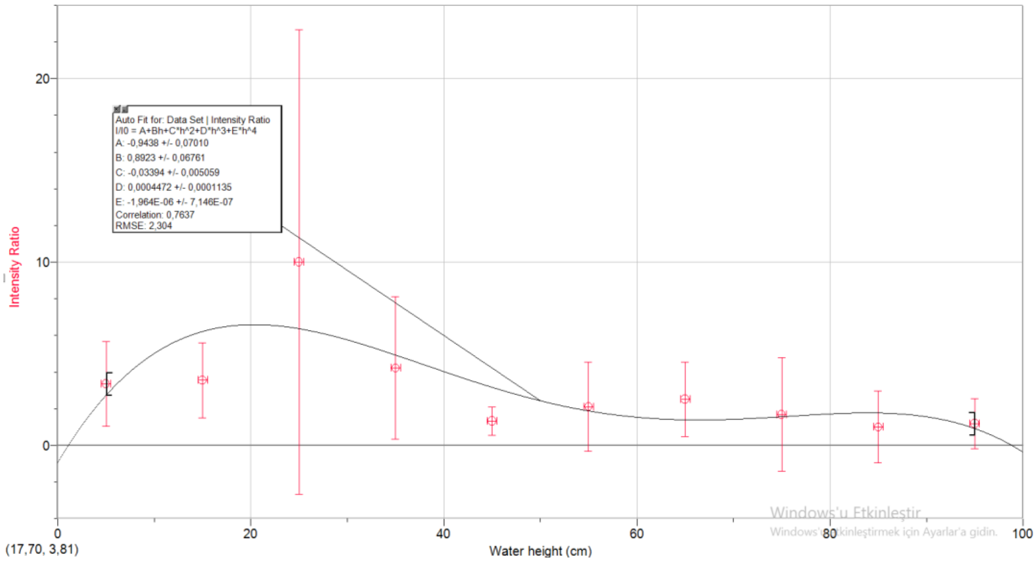

Figure 5. Relationship between intensity Ratios and Air Column Length.

Because sound propagates through air, air column length is a key factor to analyze the concept. The graph shows that as water height increases, the column length decreases. In the graph maximum intensity ratio is observed at 25 cm in air column length. This observation is consistent in the condition of closed-open air column which is stated in the background information.

Comparing these graphs highlights the importance to analyze datas correctly and the importance of data processing. While first graph shows an increasing trend, other two graphs' distribution were different. Figure 4. and Figure 5. directly addressed the intended research and allowed to compare the concept with initial predictions.

Linearization Of The Graph

Initial relationship for the graph of water height and intensity ratios is a logarithmic relationship. This relationship is not linear which means that error propagation and percentage error cannot be calculated properly. To achieve accurate error propagation and percentage error values the relationship between L and I must be linear. For this reason the graph must be linearized. By deriving the initial logartihmic equation, a new equation can be derived. The equation is given by:

$$\Delta L = 10\log(I_r)$$

$$I_r = log^{\frac{\Delta L}{10}}$$

Using this equation linearized graph of Intensity Ratio and Water Height can be graphed:

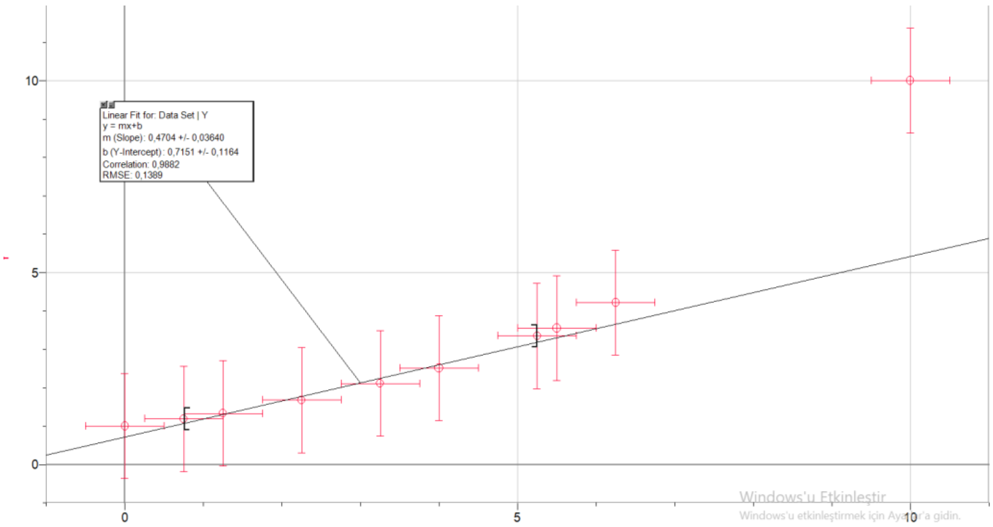

Table 6. Linearized Graph of the relationship between Water Height and Intensity Ratios

From this graph accurate percentage error and error propagation can be calculated. As this shows a linear graph the calculated percentage errors and error propagation is accurate and reliable. This assumption is correct as there is a high correlation factor which is 0.9882. This value is higher than 0.97 therefore represents that there is a strong correlation between these two variables.

Overall, this analysis supports the idea that sound intensity is dependent on air column length. Even though there are uncertainties in the calculations, results obtained is related to the theoretical ideas. In short, even though there were high percentage errors were present, maximum intensity shows that resonance effect is not only resulted from random uncertainty.

8.Evaluation

In general, this essay shows that the effect of water height on sound intensity. The research question is explained and analyzed in detail with the use of calculations such as , mean sound level, air column length, uncertainty and intensity ratios. The calculations and the tables given shows a clear understanding of the research question and the topic itself. This essay not only shows the usage of physics concepts but also mathematical calculations to improve the understanding. The transition to the intensity formula from the measured sound levels in decibels shows that in order to achieve physical meaning, additional mathematical knowledge is required.

The usage of different data calculations strengthened the reliability and accuracy of this essay. With the help of such calculations limitations of decibel scale is understood. This shows that physical understanding needs other logarithmic equations that address directly to the energy. To add more, this essay also shows a clear understanding of the topic and the experiment. As standing waves, resonance and wave reflection are mentioned both in the background information and used in calculations to explain the datas. This shows that theoretic knowledge is used both descriptively and analytically.

Even though the experimental setup and procedure was simple, it has shown the physical concepts and addressed the research question successfully. Also, because of this simplicity, it is shown that the experiment can be re-done easily when achieved suitable conditions.

In general, this essay shows how critical thinking, effective use of science and careful calculation can be applied to abstract physical concepts. The results taken from the experiment are supported by data analysis. This investigation also addressed the research question using experimentation and analysis.

8.1 Limitations

1- The sound measured were observed with the usage of smartphones which may include systematic errors.
2- Background noises can not be eliminated fully therefore it may have affected the datas achieved.
3- Water height is measured by intervals and midpoints are used during the calculation process. Therefore, this might create uncertainty in the air column lengths.
4- The experiment is conducted in an open laboratory. Therefore there may be an increase in the measurement of interference.

8.2 Strengths

1- Multiple trials were taken for each trial. Therefore, it increased the reliability and the accuracy of the datas achieved.
2- Clear sound levels observed during the experimentation therefore the calculations were made easily.
3- Methodology was simple. Therefore the experiment can be re-done easily under same conditions.

9.Conclusion

This research question showed how the change in water height affected the sound intensity measured by a frequency measure application. Calculations showed that sound intensity does not fully depend on water height but dependent on the length of the air column. Also the analysis showed clear calculations to further investigate this topic. As the sound intensity ratio showed that ,in (70-80 cm), was 10 times higher than the reference sound.

In addition, this essay reflects the importance of data analysis and suitable presentation of the calculations when investigating physical concepts. The use of sound intensity ratios allowed the results to be more accurate. It also allowed the concept to be explained in terms of energy transfer. This increased the reliability of the investigation. In conclusion, even with such easy experimentation abstract physical concepts can be understood by careful calculations, analysis and data transformations.

10.References

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