How does the distance of a heat source from a thermistor affect the amplitude of sound emitted by a buzzer?

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Contents

Introduction

When I was young, my parents had bought a new oven, although this oven was brand new the oven used to over heat up as the temperature reading used to read the temperature as less than what is actually was, so the oven used to try to match the temperate it was set at. After several visits of the technician and evaluating the issue, the problem was a simple sticker that was on top of the temperature sensor. The technician informed us that the sticker was acting as a thermal insulator and blocking the heat to reach the temperature sensor. This got me thinking if such simple stickers of 0.1mm can make such a huge difference how will the thickness of insulator used to protect the thermistor in temperature alarms would affect the sensor and temperature readings and produce no alarms during an emergency.

I carried a trial experiment but due to the thermistor not being very sensitive and the insulator I was using was blocking a very high percentage of heat, and changing the thickness of the insulator was giving a very small change which was producing very inaccurate results, so I decided to use air as an insulator which worked in the trial experiment.

Background information

A thermistor is a type of temperature sensor that works on the principle of changing resistance with changes in temperature. It is made of a semiconductor material such as ceramic or polymer, which has a high temperature coefficient of resistance. This means that the resistance of the material changes significantly with changes in temperature.

The term thermistor comes from "thermal" and "resistor". A thermistor is a resistor for which the resistance changes significantly with a change in temperature (Resistor-guide, n.d.); and therefore, it is a temperature sensitive resistor, because the resistance of a thermistor decreases with increasing temperature.

They are also found in almost any application that needs heating or cooling protection circuits for safe operation (THERMISTOR BASICS – Wavelength Electronics, 2020). Thermistors are divided based on their conduction model. Negative Temperature Coefficient (NTC) thermistors have less resistance at higher temperatures, while Positive Temperature Coefficient (PTC) thermistors have more resistance at higher temperatures. Hence, a PTC thermistor's resistance is directly proportional to temperature (PTC Thermistor Vs. NTC Thermistor, 2020).

The thermistor symbols are:

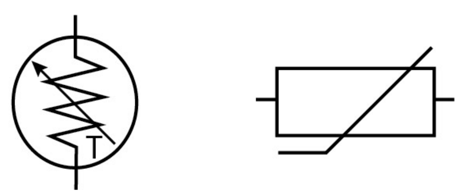


Figure 1: Thermistor Symbol
(THERMISTOR BASICS – Wavelength Electronics, 2020)

In contrast to other sensors, thermistors are nonlinear, meaning that the points on a graph showing the relationship between resistance and temperature will not form a straight line. The thermistor's construction determines the placement of the line and the degree to which it varies. A typical thermistor graph appears as follows:

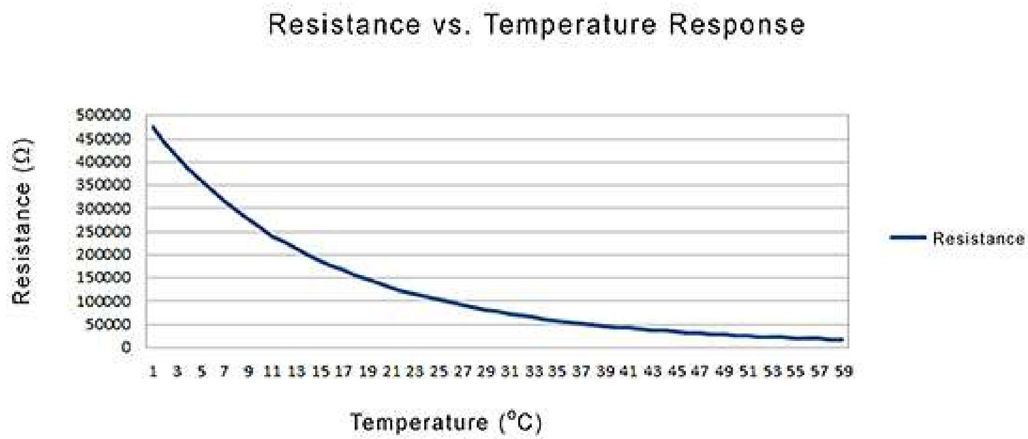


Figure 2: Graph showing resistance vs temperature

Source: (THERMISTOR BASICS – Wavelength Electronics, 2020)

Thermistors are a type of semiconductor, A semiconductor device is an electronic component whose function is dependent on the electronic properties of a semiconductor material (mainly silicon, germanium, gallium arsenide, and organic semiconductors). Its conductivity falls between that of insulators and conductors. In most applications, semiconductor devices have replaced vacuum tubes. They conduct current in the solid state, as opposed to as free electrons through a vacuum (usually liberated by thermionic emission) or as free electrons and ions through an ionized gas (Sze, 1998).

Doping, often known as the deliberate addition of impurities, makes it simple to control the behavior of semiconducting materials. The conductivity of a semiconductor can be changed by applying an electric or magnetic field, exposing it to light or heat, or deforming a doped monocrystalline silicon grid mechanically; hence, semiconductors make good sensors. Mobile or "free" electrons and electron holes, generally known as charge carriers, are responsible for current conduction in a semiconductor. By doping a semiconductor with a little amount of an atomic impurity, such as phosphorus or boron, the number of free electrons or holes within the semiconductor is substantially increased. When a doped semiconductor includes surplus holes, it is referred to as p-type (p for positive electric charge); when it contains excess free electrons, it is referred to as n-type (*Semiconductor Device*, n.d.).

The change in resistance with temperature can be described by the temperature coefficient of resistance (TCR) of the thermistor, which is a measure of how much the resistance changes with temperature. By understanding the TCR of a thermistor and the relationship between resistance, current, and voltage, engineers can design circuits that use thermistors to measure temperature or control other circuit elements based on temperature.

The Steinhart–Hart equation is a model of the resistance of a semiconductor at different temperatures.

$$\frac{1}{T} = A + B \ln R + C(\ln R)^3$$

Where:

T is the temperature, in Kelvins (K, Kelvin = Celsius + 273.15)

R is resistance at T, in Ohms (Ω)

A, B and C are the Steinhart-Hart coefficients that vary depending on the type of thermistor used and the range of temperature being detected.

ln is Natural Log, or Log to the Napierian base 2.71828

This equation calculates with greater precision the actual resistance of a thermistor as a function of temperature. The narrower the temperature range, the more accurate the resistance calculation will be. Most thermistor manufacturers provide the A, B, and C coefficients for a typical temperature range.

To find the resistance of a semiconductor at a given temperature, the inverse of the Steinhart–Hart equation can be used,

$$R = exp\left(\sqrt[3]{Y - \frac{X}{2}} - \sqrt[3]{Y + \frac{X}{2}}\right)$$

Where:

$$X = \frac{1}{C}\left(A - \frac{1}{T}\right)$$

$$Y = \sqrt{\left(\frac{B}{3C}\right)^3 + \frac{X^2}{4}}$$

A thermistor is a type of transducer that can convert thermal energy into electrical energy. Which can then use a buzzer to convert that electrical energy into sound. Specifically, a thermistor changes its resistance in response to changes in temperature. This change in resistance can be measured and converted into an electrical signal, which can be used for a variety of applications.

For example, thermistors are commonly used as temperature sensors in a variety of devices, including thermostats, ovens, and refrigerators. In these applications, the change in resistance of the thermistor is used to determine the temperature of the device, which can be used to control heating or cooling systems. They can also be used in industrial applications, such as monitoring the temperature of machinery or detecting hot spots in electrical systems. In these applications, the thermistor is often used as part of a larger sensor system that includes amplifiers, filters, and other components to convert the thermistor's output into a usable signal.

A sound wave is a vibration that travels through a medium as an acoustic wave and is formed of compressions (high pressure regions) and rarefactions (low pressure regions). When an electric current is delivered to the buzzer, the ceramic disk contracts or expands, causing the surrounding disk to vibrate and emit sound waves (Vedantu, 2022).

Design

Research question

How does the distance of a heat source on a thermistor affect the amplitude of sound emitted by a buzzer?

Hypothesis

My hypothesis is that the amplitude of sound emitted is inversely proportional to the heat source distance on the thermistor a. As the distance of the heat source increases, the resistance of the thermistor also increases, and hence it takes a larger share of the supply potential difference and as a result the voltage across the buzzer decreases and it sounds quieter.

Variables

Table Showing the dependent and independent variables in the experiment	
Independent Variables	Distance of heater from the thermistor: The length is measured using a ruler in increments of 0.5cm, starting from 0.0cm to the 5cm mark.
Dependent Variables	Sound intensity from the buzzer: Measured with a Neulog sound intensity sensor (connected to a computer via a USB cable) and Neulog data logging software.

Table: 1 showing the independent and dependent variables of the experiment

Table Showing controlled variables in the experiment		
Controlled Variable	**Reason**	**Method**
Supply voltage across the thermistor and the buzzer	If the potential difference across the thermistor was altered, then the sensitivity of the thermistor would be different and again it would invalidate the correlation of the sound intensity to the heat and thus affect the trend line.	A power unit was used to output a constant supply of potential difference to the thermistor and buzzer circuit throughout the experiment. The power unit dial with selective voltage was used.
Distance between Neulog sensor and buzzer	A change in the distance from the buzzer to the sound sensor between trials would cause a random error in the sound intensity readings because the number of air molecules between would vary, causing the number of vibrations picked up by the sensor to vary and affect the trend line.	The sensor was placed exactly at the end of the circuit to ensure that the buzzer was at a constant distance from the sensor throughout the experiment.
Background sound in the environment	Different background noises can produce different results, invalidating the sound intensity-heat correlation and affecting the trend line.	I closed all the windows in the room and put curtains over them to minimize the amount of sound from outside.
Supply of voltage across the heater	If the heater's potential difference was changed, the heater would produce a different temperature, which would affect the thermistor and the buzzer's sound output, invalidating the correlation between sound intensity and light intensity and affecting the trend line.	A power unit was used to output a constant supply of potential difference to the heater throughout the experiment. The power unit dial with selective voltage was used.

Table: 2 showing the controlled variables of the experiment

Apparatus and Materials

- 6V DC Buzzer
- Electronic Heater
- Thermistor
- Bench Power unit
- Retort Stand and Clamp
- Variable Resistor
- Transistor
- Computer
- Meter Rule
- Neulog Sound Sensor
- Neulog Data Logging Software

Circuit diagram and experimental set up

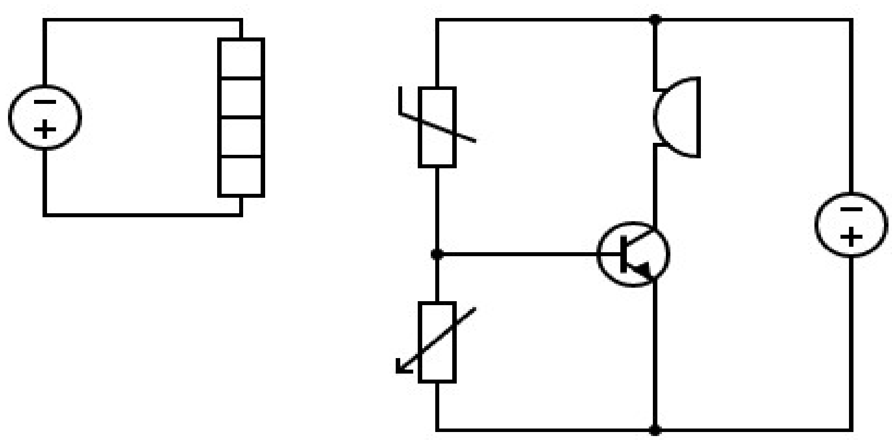


Figure 3: Circuit diagram and key of the electrical components used

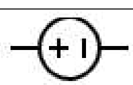
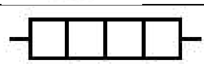
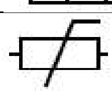
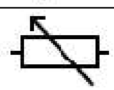
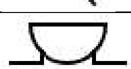
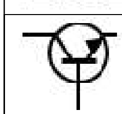
Table showing the key for the circuit diagram	
Key	
Symbol	Component
	DC 9V power source
	Electronic Heater
	Thermistor
	Variable Resistor
	Buzzer
	Transistor

Table: 3 showing the key for the circuit diagram used in the experiment

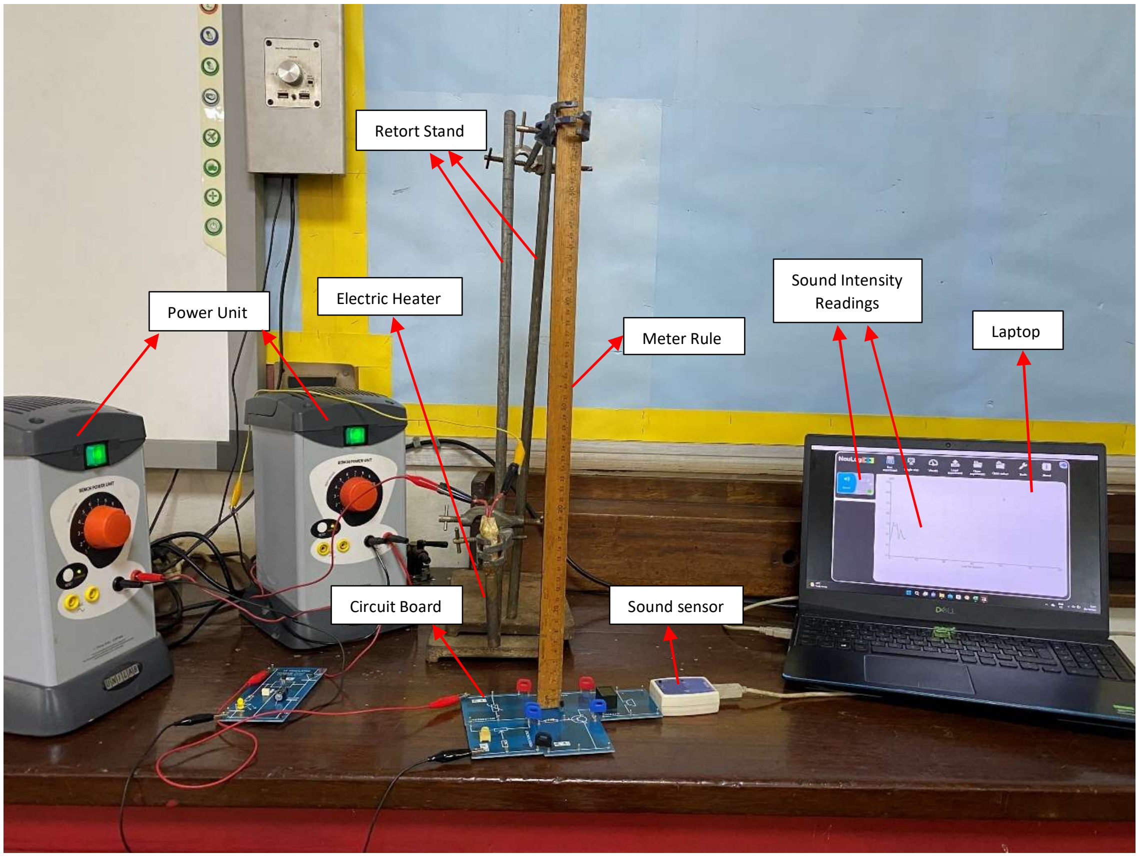


Figure 4: Picture of the experimental set-up

Procedure

1. The experiment was setup as indicated above (figure 4).
2. The initial reading from the sound sensor was recorded as it is the value for the sound intensity of the surrounding environment.
3. The distance across the heater and the thermistor was then increased by adjusting the retort stand. The corresponding sound intensity value was noted.
4. The steps above were done three times so that an average sound intensity could be found. This reduces the random error in the sound intensity.
5. The procedure was repeated for the lengths of 0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5 and 5cm. This was done by adjusting the heater height using the retort stand. The range also gives enough information for analysis. The maximum length l chosen was 5cm because the buzzer made no sound difference beyond that as the thermistor was unable to pick up any heat.
6. The findings were entered into an appropriate table, and a graph of sound strength vs distance was generated and analyzed.

Safety precautions

In order to avoid blowing the heater, which is designed to function normally up to a maximum voltage of 12 volts, the voltage that was being delivered to the electric heater needed to be regulated. Keeping the voltage at a manageable level was important for a number of reasons, one of which was to eliminate the risk of receiving an electric shock from making contact with any exposed crocodile clips. In order to achieve this regulation, a power unit where a maximum of 9 volts was set in order to guarantee that the supply did not exceed 9V. This ensured that the heater did not blow and that the voltage level was safe for me to conduct the experiment with low negligible risk. Because the system was protected from any outside influence that could have altered the voltage settings, anyone using it was protected from the possibility of receiving an electric shock. In this investigation There was no environmental and ethical issues associated.

Figure 5: The power unit and the voltmeter used to regulate the voltage

Data Collection

Table Showing the measured sound intensity from the buzzer.					
Distance from heat source d/cm $\Delta d = \pm 0.01cm$	Sound intensity Si / dB = ΔSi=± 0.1 dB			Average Sound Intensity S / dB	Error in SI ΔS / dB
	Trial 1	Trial 2	Trial 3		
0.00	126.2	126.2	126.3	126.2	±0.1
0.50	96.0	95.4	96.4	95.9	±0.5
1.00	82.0	81.2	78.3	80.5	±1.9
1.50	69.2	70.2	70.7	70.0	±0.8
2.00	62.9	63.8	62.1	62.9	±0.8
2.50	59.2	60.1	59.1	59.5	±0.5
3.00	58.5	58.3	58.5	58.4	±0.1
3.50	58.0	57.9	58.1	58.0	±0.1
4.00	57.6	57.8	57.4	57.6	±0.2
4.50	57.2	56.8	56.9	57.0	±0.2
5.00	57.1	56.8	57.0	57.0	±0.2

Table 4: Shows the measured sound intensity from the buzzer.

Average background noise: 57.0 dB

Data processing and error propagation

The average sound intensity emitted by the buzzer is determined using the data gathered in Table 4. The following table shows the results of the calculations for the uncertainty in the recorded sound intensity;

Table showing average sound intensity calculations as well as calculations for sound intensity uncertainty.	
Average sound intensity calculation: $$S_i = \frac{trial_1 + trial_2 + trial_3}{3}$$	
Calculation for error in sound intensity: $$\Delta S_i = \frac{(S_{i_{max}} - S_{i_{min}})}{2}$$	
Example, When the distance is 0.5cm:	
$S_i = \frac{96.0 + 95.4 + 96.4}{3} = 95.9dB$	$\Delta S_i = \frac{(96.4 - 95.4)}{2} = 0.5dB$

Table 5: Shows average sound intensity calculations as well as calculations for sound intensity uncertainty.

Graphical Representation

A graph showing sound intensity (db) against distance from the heat source (cm)

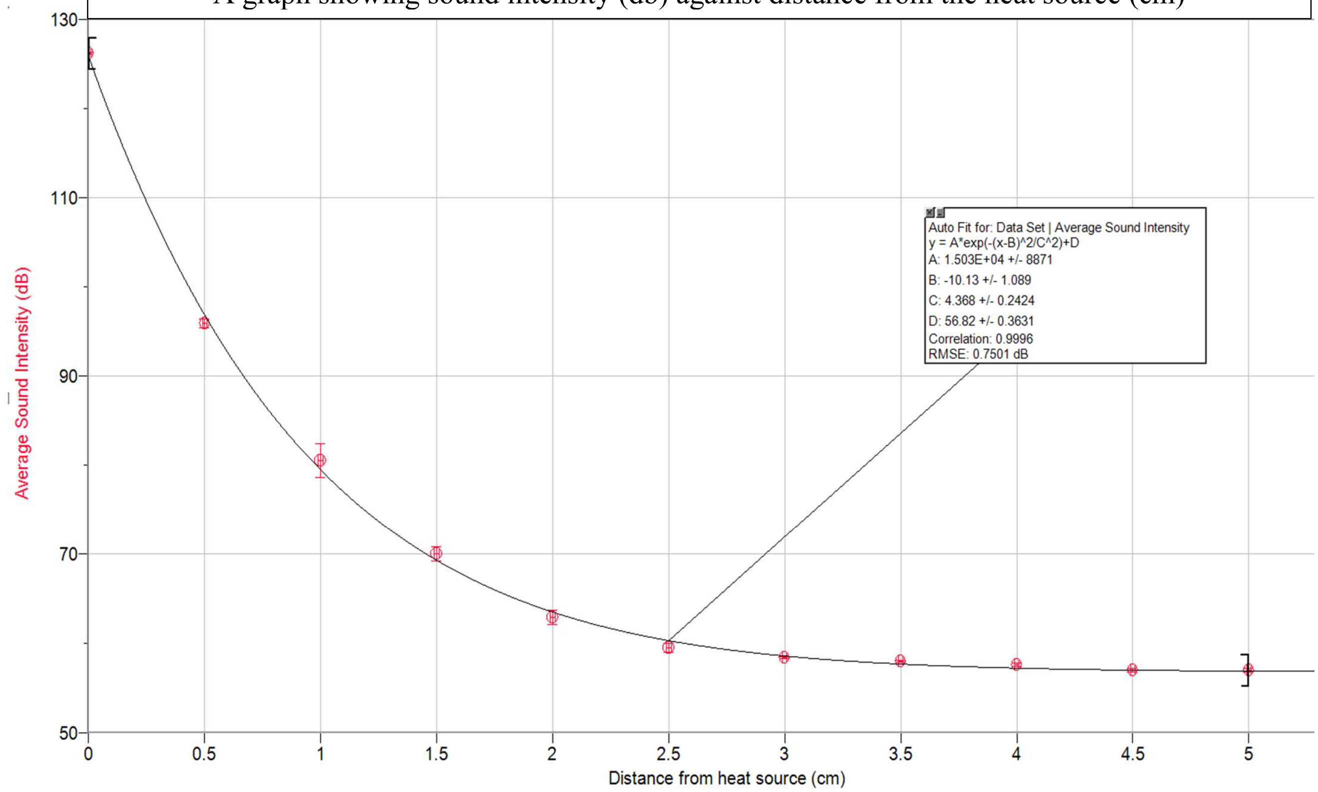


Figure 6: Shows a graph of Sound Intensity against Distance

The error bars on the above graph show that there is only a small amount of uncertainty in the sound intensity. I used digital technology to measure the sound intensity, which produced more accurate measurements, and as a result the error bars for sound intensity are small.

Graphical analysis

From the graph of sound intensity versus distance of heater from the thermistor, it is evident that the relationship between the two is nonlinear, indicating that the two values are not directly proportional to one another as opposed to my hypothesized. In fact, the graph of sound intensity versus distance is an exponential curve, and it asymptotically approached nearly 57 dB of sound intensity (horizontal asymptote at 57dB). This graph indicates that the buzzer has a minimum current over which it cannot be softer. There is a Y- intercept at 126.3 indicating the maximum amount of sound intensity that can be emitted is 126.3.

Idealistically, one would expect the graph to become a straight line at the 0 mark on the X-axis, but the graph shows a positive vertical shift, indicating systematic error in the readings. The positive vertical shift corresponds to the initial sound level in the physics lab when I conducted the experiment, which can be attributed to noise level picked up by the Neulog sound sensor. As a result of this systematic error in sound intensity, the graph of sound intensity against distance of thermistor is shifted vertically upwards.

It is evident from the graph that not all of the points lie on the curve (line) of best fit, indicating the presence of random errors in the experiment. As I gathered data, I noticed that background noise would cause a fluctuation, which may have been the cause of the random error in the readings that can be seen on the graph. This

Conclusion

In conclusion as the distance between the heater and thermistor increases the amplitude od sound decreases.

The distance of a heat source from a thermistor affects the amplitude of sound emitted by a buzzer due to the change in temperature that affects the resistance of the thermistor. As the distance between the heat source and thermistor increases, the temperature of the thermistor decreases, causing its resistance to increase. This change in resistance affects the current passing through the circuit and the voltage across the buzzer, which in turn affects the amplitude of sound produced by the buzzer. Based on this relationship between the dependent variable (amplitude of sound emitted by the buzzer) and independent variable (distance of the heat source from the thermistor), we can conclude that the amplitude of sound produced by the buzzer decreases as the distance between the heat source and thermistor increases.

Although the relationship between sound and distance from the heater is non-linear, it is safe to conclude that the buzzer generates a lower sound when the heater goes further away from the thermistor. This relationship between resistance, current, and voltage is defined by Ohm's Law when there is more current going through the circuit and therefore the buzzer. Therefore, my hypothesis, that sound decreases with increasing distance, is partially correct. However, after a certain point, the sound intensity stops decreasing and the resulting graph is exponential rather than linear. Therefore, either the thermistor has a maximum resistance, resulting in a minimal current being able to pass through the circuit, or the buzzer and its surroundings have a minimum amplitude of sound it can emit.

We can also conclude this finding using the formula $I \propto A^2$. As observed from the graph the intensity of the sound wave produced by the buzzer is almost proportional to the square of its amplitude. As the distance between the heat source and thermistor increases, the temperature difference detected by the thermistor decreases, resulting in a lower voltage output from the thermistor. This lower voltage output is then amplified by the circuitry of the buzzer, resulting in a lower amplitude of sound produced. Therefore, the relationship between the distance of a heat source from a thermistor and the amplitude of sound emitted by a buzzer is inversely proportional. As the distance increases, the amplitude decreases, and the intensity of the sound wave produced by the buzzer decreases proportionally to the square of the amplitude.

In any case, this indicates that any future investigations that expand on this study paper will require a deep understanding of the sensitivity of the thermistor and buzzer used is crucial for any future experiments to build on this research paper.

Strengths

Strengths	Impact
Use of Neulog sound sensor and the related data logging software for data collection	Because of the precision of the digital instrument, uncertainty in measurements has been greatly reduced, allowing for more accurate results.
Multiple trials	Since the Neulog sound intensity sensors' readings had a tendency of randomly fluctuating, the research was conducted many times to eliminate the random error in the sound intensity by averaging the results of the tests and getting at a more precise measurement.
The sound sensor was maintained at a fixed distance from the buzzer.	By maintaining a consistent distance between the buzzer and the sound sensor throughout the experiment, this minimized the random error in the sound intensity data that would have otherwise impact the trend line.

Table 6: Shows the strength of my experiment and impact of the strength on result

Limitations and Improvements

Weaknesses and limitations	Impact	Possible improvement
The amount of current going through the buzzer wasn't measured	It was hard to tell whether the current was fluctuating or steady and this would affect the output intensity. Because of this, I couldn't figure out why the graph is exponential and the sound intensity stays the same after 3cm, which changed the way the trend was shown.	Add an ammeter between the buzzer and the thermistor to see if the amount of current flowing through the circuit goes down as the light heat decreases. If not, we can assume that the capabilities of the buzzer and/or thermistor are themselves a limitation. This would make the trend shown on the graph more accurate.

The experiment was conducted while classes were going in, producing a lot of background noise.	Because this experiment was conducted during the school day, there was a lot of background noise in the room, so all of the results for sound intensity are overestimates and hence the graph is shifted upwards.	To reduce the systematic error in the sound intensity readings, it is best to do the experiment on a weekend, at a quieter time of day, or in a soundproof environment.
Large variation between heat intensity values	I opted for a thermistor distance of 0.5cm, which may not be optimal as it yields a less precise curve of best fit.	Altering the distance by merely 2.5cm instead of 5cm would result in a more accurate curve of best fit being plotted because there would be a smaller uncertainty in the distance.

Table 7: Shows the limitations, impact and a possible improvement.

Extension

Keeping the idea of insulators, a possible extension to this experiment is to investigate how the type of heat source affects the amplitude of sound emitted by the buzzer. I could use different heat sources, such as a candle, a light bulb, a hot plate and measure the amplitude of sound emitted by the buzzer at different distances from the thermistor for each heat source.

Another extension could be to explore how different materials affect the amplitude of sound emitted by the buzzer. I could place the thermistor and heat source in different materials, such as air, water, or different solids, and measure the amplitude of sound emitted by the buzzer at different distances from the thermistor for each material.

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