1. Librado
2. Max
3. Librado –

How sound is affected by a medium. Sound travels through a compression wave. Often this is visualized as a pressure wave, and shows sound as it travels through space in a consistent form. However, in actuality, it is the interaction between molecules reflecting/bouncing off of each other that is resemblant of the wave visual that we see. For this reason, gas, opposed to liquids or solids, is the slowest medium in which sound can travel in. By observing the frequencies as they correspond to different gaseous mediums, it can give insight into how sound is affected through different mediums.

Density of gases. As can be seen from solids and liquids, density indicates how fast sound travels. The more dense the faster sound travels through that medium. By observing the gases and their corresponding density, a possible generalization can be made about their density as it correlates to their frequency/speed.

How temperature affects the speed of sound. The temperature of a gas has an effect on molecular interaction greatly. By increasing temperature, the molecular velocity of interacting particles and frequency of collisions increase. By observing the resonant frequencies of gases, we can determine the relations that the temperature may have on the speed of sound.

By finding the resonant frequency, the Boltzmann constant can be determined.

The equations below were critical to help determining our values throughout the experiment.

1. Max –

We used an acoustic cavity, which was a small, cylindrical cavity that had a static volume, with a sound wave generator on one side and a sound wave detector on the other. This was fed the gas of our choice through a series of sealed tubes which were emptied out using a vacuum before each new gas was put into the cavity. The cavity itself was inside of an insulated cardboard box so that the temperature would be unaffected by the surrounding air, but this was only so good. To test the response of the gas at a given range of frequencies, a program was set up on our lab computer which would scan through a set frequency range in Hz at a given speed; the number of steps for the program to divide this range into could also be specified, along with the length of time used for the data collected at that frequency, this would result in more or less precise data depending on the settings used. Using peripheral electronics we measured the pressure, temperature, and vibrational strength of the sound waves in the cavity, which we then analyzed with extraneous digital software. The vibrational strength of the gas was measured in voltage, as a flexible membrane inside the cavity vibrated with a coil of wire attached to the side not present in the gas. That coil was connected to a voltmeter, and adjacent to a permanent magnet which would induce a voltage in the wire as it moved through the magnetic field of the magnet; thus we knew the relative strength of the vibrations in the cavity. Each run of data collection was done in a small enough period of time so that the gradually increasing temperature hopefully did not negatively affect the assumption that we were under relatively constant temperature for the whole experiment.

1. Max –

Error was reduced through a number of methods, first being the insulated box that the cavity was placed in, thus preventing outside heating sources from having a significant effect on it.  Since the volume and temperature were being kept constant, the pressure could also be assumed to being kept constant, under the assumption  of the ideal gas law; the valves were also sealed such that the amount of gas could not increase during the experiments.  Temperature only increased by .44 K on average, and pressure by .064 torr.  We took very slow runs of data to make sure it was averaged as well as it could be for each data point, and had a high number of steps to make sure the peak of the data was well defined.  Error was also reduced by being exceptionally careful with the movement of gas into and out of the cavity before and after each experiment.  We would: Carefully removed the previous gas from the cavity and surrounding tubes. Connect the metal hose for adding gas to the cylinder of our choice.  Vacuum out everything until the pressure reached -0.8 torr as read by the overhead digital readout.  Vacuum out the metal hose connected to the gas cylinder as well as the chamber behind the needle valve.  Add gas from the main cylinder to the regulator chamber.  Add gas from the regulator chamber to the needle valve chamber.  Add gas from the needle valve chamber to the tubes and gas chamber.  Seal the entrance to the gas chamber.

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This is a graph of Argon, with a peak frequency of 1823 Hz. This scan was run through a slow scan of fifteen seconds per point. Implying that it sat at each value for about 15 seconds to accumulate data for that value. It ran through exactly 150 points. Allowing each frequency to be analyzed, going from 1750 to 1900. At the exact frequency value of 1823, the peak is obtained. And using this as the peak, it should be expected that over the same interval of time that had passed before the peak should yield the same height for after the peak. Therefore by analyzing two equidistant points from the peak, it should be expected that they have the same height. However it was observed that this is not true. In fact, consistently through all of our results it was obtained that the points that laid to the right of the peak always had a higher value than those of the points on the left. Our current leading theory is that it is caused by Temperature, and that by an increasing temperature it causes the resonant frequency to also increase. This would lead to the velocity in turn increasing for sound within that medium. This makes sense with physical intuition, since as the temperature increases, the velocity of traveling molecules also increases, yielding a greater frequency.

Although this error may have existed in this graph, the temperature does not affect our observed resonant frequency because for each frequency value the temperature was accordingly well documented by the program.

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We determined that Helium did not possess any unique qualities that should allow for some interaction that the other gasses did not experience; further, it should behave most like an ideal gas since it is the simplest particle that we studied and forms no bonds.  There were no significant differences in the conditions that Helium was tested in compared to other gasses, so it could not be a procedural error leading to Helium’s significantly larger relative error in it’s calculation of the Boltzmann constant and the speed of sound.  Thus, we concluded that it must be the sample of Helium itself that was leading to error in some manner.  The most likely culprit is contamination with outside air, which would increase the average molar mass of the gas.  We tested the data and used an adjusted molar mass for Helium, using our existing resonance peak data, to determine that a 1% contamination of the sample by ambient air would lead to a significantly increased result for the calculation of the Boltzmann constant.  Thus, the sample may have been contaminated, but if it was, it must have been less than 1%.  Helium was the first gas that we experimented with besides ambient air, so it is possible that we did not properly vacuum out the tubes or the resonance cavity and ended up with some contamination, or that some previous group contaminated the sample with poor procedure.

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We used the data for the resonance peak along with the temperature at that peak to calculate the Boltzmann constant for each gas we studied, along with Equation 2.  Then we averaged them across all 6 relevant measurements and compared that average to the expected value.  The average value was decently close to the expected value, having only 2.32% error, and being within -.92 standard deviations from the expected value, something entirely within a reasonable range for a measurement like this.  There may have been minor instrumental measurement errors picked up from the various electronics we had to use, geometric imperfections in the shape of the cylinder that would hurt resonance values, or inaccuracy in the length of the cylinder due to manufacturing problems.  We determined that the speakers could not have been impacting the length of the cylinder in any manner, so that was not a source of error, and the pressures for the gasses remained within plus or minus .06 torr in general, so the ideal gas law was being obeyed the whole time.  The digital software may have contributed some error, since we only took data, at best, every 1 Hz, when we could have done better if we had chosen to.  The ideal gas law was also likely slightly inaccurate here, as it assumes 4 things (switch to next slide) and the 1st and 3rd were likely not entirely true in most cases.  Thus, small corrections may have been needed to the equations that we ended up using.  Additionally, the specific heat ratio for all the gasses we tested was constant under such small temperature changes at the ones experienced here.  The largest sources of error were likely the Helium measurements, which we suspect may have been due to contamination of the substance explained previously, but overall the decent error we ended up with was quite acceptable.

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Using the binary gas mixture equation, we were able to determine what the expected frequency should be and compare it against our measured frequency.  Discrepancies in the two values were likely due to the gas not obeying the ideal gas laws as closely as we would like, along with slight unaccounted for impurities in the air driving the resonant frequency down, or even the equipment we were using causing slight errors that compounded with the previous mentioned sources of error.  There was little error induced in the pressure or temperature changes, since specific heat capacity for air barely changes (in the range of millionths) for the minimal (.4 torr or .2 K) changes we saw over the course of the experiment, so that did not induce any error in our experiments.  Over all the measurements were fairly accurate though, only being off by 0.5% or less.

We were also able to use the resonant frequency of the ambient air to confirm the speed of sound in air to within 0.05%, an extremely great measurement that confirms the validity of the equations we had used thus far.

The exhaled air after 3 minutes of exercise exhibited a noticeably smaller resonant frequency compared to both dry ambient air and dry exhaled air, which we determined to be due to the increased concentration of carbon dioxide.  All gasses were tested under very similar conditions and the removal of moisture from the air only contributed to a small reduction in the resonant frequency.  Thus, the increased carbon dioxide in the air I breathed out caused a decrease in the resonant frequency because it increased the average mass of gas particles in the cavity.

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In this chart we see the mass as it relates to the speed of sound in that gas. As mentioned earlier, with solids and liquids, the density and speed had a positive relationship. With the increase in density there was an increase in speed. However, for gases, we can see that the least dense element that we observed, which is Helium, in fact had the greatest observed speed. This indicates that a change in perspective is necessary when viewing these elements. As density increases, the speed actually decreases. This is not intuitive for a solid. However, for solids, the elements remain very close to each other, and with each successive collision of atoms, the initial velocity of the elements is near its peak when it had accelerated, compared against gases, which lay fairly far apart, and when these molecules collide with another, they lay fairly far apart. This causes their velocity to decrease over time as they travel to the next molecule in the wave pattern, making the velocity a fraction of what it was when it initially received impact from the source of the sound. Therefore, the mass of the colliding molecules will become a large factor in affecting the velocity of the traveling wave. By looking at conservation of momentum, we can more easily understand why a heavier element like Argon would have a lower velocity than a very light element like Helium.

This graph resembles a similar function that we would expect from the equation that relates the speed of velocity and mass. From the graph you may notice that carbon dioxide appears to be a bit lower than what youd expect from looking at this cluster of values to the left of it. We believe this may be true for carbon dioxide because of the complexity that exists within this molecule, such as higher degrees of freedom and triple bonds that may cause it to have a lower overall velocity, possibly caused by a greater inertia/mass that makes it harder to move than expected.