PHYSICS

The Speed of Sound – Pavillion

Aim: To measure the speed of sound in air.

Theory:

Sound is a form of mechanical energy transferred by the vibration of molecules within the medium. Hence, sound requires a medium in which to travel. Sounds travels via longitudinal waves, where the transfer of energy from one particle to the next is the basis for how it travels through the medium. Given that sound waves are longitudinal, particles are displaced from their original position, and therefore consist of a kinetic energy. While the speed of such particles is very great to cause particle collisions, the speed of the sound wave itself is less than the speed of the particle movement. In air at 0°C, sound waves travel at approximately $331ms^{-1}$.

Through other mediums however, sound waves can vary in speed due to varying factors. Remembering that sound is a vibration of kinetic energy passed from molecule to molecule. The closer the molecules are to each other and the tighter their bonds, the less time it takes for them to pass the sound to each other and the faster sound can travel. It is easier for sound waves to go through solids than through liquids because the molecules are closer together and more tightly bonded in solids. Likewise, it is harder for sound to pass through gases than through liquids, because gas molecules are further apart. For sound travelling through air itself though, there is one factor which alters the speed, that being temperature.

Heat, like sound, is a form of kinetic energy. Molecules at higher temperatures have more energy, thus they can vibrate faster, causing the sound wave to travel more quickly. The formula for the speed of sound in air for any given temperature is $v = 331ms^{-1} + 0.63ms^{-1}T$ where v is velocity (ms^{-1}) and T is the number of degrees above 0°C. Therefore, the speed of sound rises by $0.63ms^{-1}$ for every 1°C increase in temperature.

However, when calculating the speed of sound in air, taking into consideration air temperature is something that occurs secondly. Firstly, the speed of sound itself must be calculated through the formula: $Speed = {}^{Distance}/_{Time}$ where speed is in metres per second, distance is in metres and time is in seconds. Ignoring the effect of temperature as well as other external factors, the speed of sound can be tested and proven through dividing the distance a sound travels by the time it takes to get there.

Lastly, sound can be reflected by a surface such as a wall. However, the effectiveness of the reflection also depends on the type of surface. If a sound wave hits a flat surface, it will be reflected back in the direction it came from, continuing with the same level of diffraction. However, while sound reflects off jagged surfaces, it reflects in all different directions and therefore it becomes difficult to hear. If however the sound wave hits a parabolic surface, it will be reflected in a straight line. A sound wave will continue to bounce around a room, or reverberate, until it has lost all its energy. A wave has some of its energy absorbed by the objects it hits. The rest is lost as heat energy. As a result of reflection, it is possible to measure the time taken for a sound to return back to you, thus measure the speed of sound, given the distance to the point of reflection and back is measured.

Apparatus

- Stopwatch
- Two lengths of metal
- Trundle wheel or measuring tape
- Thermometer

Method

In order to test the speed of sound using the formula ${Distance}/_{Time}$ we must be able to record the time it takes for the sound to travel and measure the distance it travels. In order to do so we must reflect sound off a surface, so that we are able to hear the sound being reflected a short period of time after the initial sound was made.

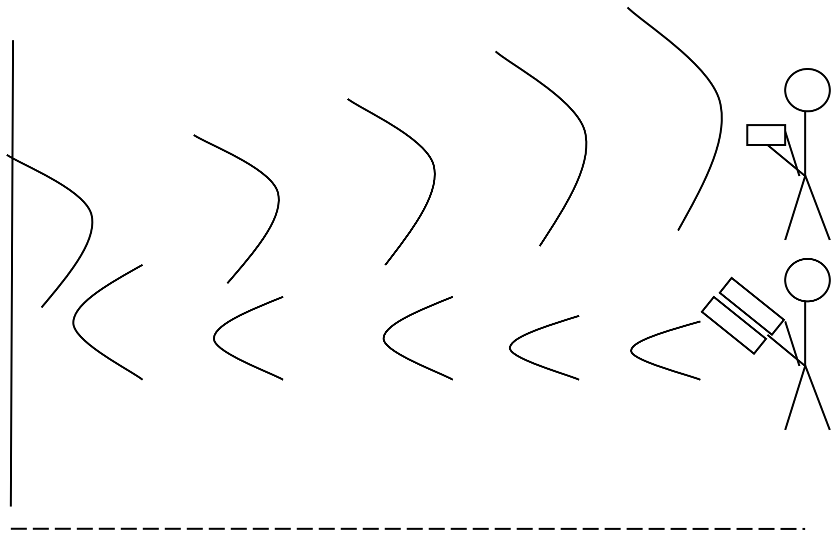
Using a trundle wheel, we measured a distance of 50m from a pavilion to a point on the oval. Given that we will be recording the distance for the sound to travel to the pavilion and back again, this distance must be doubled so that the sound is really travelling 100 metres.

Using two long pieces of metal, one person must bang the two pieces together, creating a loud sound, while another person records how long it takes before the reflected sound comes back. As this time is so minute, when hitting the two pieces of metal together, the person must synchronise the next hit with the echo and do this for ten time intervals, or 11 hits of the metal where the time starts recording on the first hit. As a result, the total distance the sound travels is 1000 m with the time recorded being the time it takes to travel that 1000 m.

To increase the accuracy of the results, we must repeat this process five times and record five different times, before calculating an average speed, and thus an average speed. However, to reduce the impact of human tendencies and differences in reaction time, five new times must be recorded where there is a new person timing. This gives us two different values for the speed of sound. The speed of sound is calculated through the equation ${Distance}/_{Time}$ where the distance is 1000 and the time is what was recorded with the stopwatch.

In our case, we recorded the speed of sound to be 303ms^{-1} the first time and 370ms^{-1} the second time. Now that we have two values for the speed of sound, it is important to take into consideration the effect of the temperature, so that we are able to compare it to the real value of the speed of sound where the temperature is 0°C. Using a thermometer, we measured the temperature to be 18°C. Now, given that the speed of sound increased by 0.63ms^{-1} for every one degree increase in temperature, we are able to record the speed of sound at 0°C through using the equation: $Speed\ of\ sound\ at\ 0°C = Recorded\ Speed - (0.63 \times 18)$. Through substituting in our initial speeds of 303 and 370ms^{-1}, we received values of 292 and 358ms^{-1} respectively for the speed of sound at 0°C.

Diagram



Results/ Calculations

Time taken for sound to travel 1000 m (seconds) – Trial 1	
(Trial) 1	3.55 (seconds)
2	3.24
3	3.40
4	3.21
5	3.10

Average time= $^{(3.55+3.24+3.40+3.21+3.10)}/_{5}$ = 3.300 seconds

Speed of sound at 18°C= $^{1000}/_{3.300}$ = 303ms^{-1}

Speed of sound at 0°C= $303-(0.63\times 18)$ = 292ms^{-1}

Time Taken For Sound To Travel 1000 m (Seconds) – Trial 2	
(Trial) 1	2.73 (seconds)
2	2.80
3	2.75
4	2.64
5	2.60

Average time= $^{(2.73+2.80+2.75+2.64+2.60)}/_{5}$ = 2.704 seconds

Speed of sound at 18°C= $^{1000}/_{2.704}$ = 370ms^{-1}

Speed of sound at 0°C= $369.822-(0.63\times 18)$ =358ms^{-1}

Discussion

What is the advantage in timing for ten hits rather than just one?

The advantage in timing for ten hits rather than just one allows us to produce a more accurate recording and reduces the impact of reaction time. Given that the time for sound to travel 100m is minute (approximately 0.29 seconds), it is nearly impossible for one to record this time via a stop watch accurately. However, through timing for ten hits, the impact of reaction time is significantly reduced. Given that reaction time will play a part on both starting the stop watch and stopping it again, if we were to time for just one hit then reaction time would play a great role. Yet, if we record for ten hits, only the first hit and the last hit are affected by reaction time, with the other eight hits being continuous without the need for the stopwatch to start or stop. This significantly increases the accuracy of our results. The problem with this method however, is the possibility that the person hitting the two pieces of metal together may not be hitting them exactly at the point where we hear the reflected sound, and thus the hits may be quicker or slower, hampering our results.

Why did you perform the experiment 5 times and calculate an average, rather than just do it once?

It was very important to perform the experiment 5 times and calculate an average to ensure that the results were as accurate as possible. There are many potential errors that could occur while conducting this experiment which could compromise results. These factors include delayed reaction time, miscounting the number of times the sound is reflected or hitting the metal poles too fast or too slow. Performing the experiment five times and calculating an average therefore “smooths” and minimises these factors, providing us with a more accurate answer. The more times the experiment is performed, the more accurate the average would be. However, in cases like these where significant errors may be made, it may be better to calculate the median value, rather than the mean. This would ensure that the extreme values do not influence the measure of central tendency.

Why would you expect the speed of sound to increases for an increase in temperature?

Heat, like sound, is a form of kinetic energy. Molecules at higher temperatures have more energy, thus they can vibrate faster. Since the molecules vibrate faster, sound waves can travel more quickly. However, it must be made clear that the speed of each individual particle corresponding to its kinetic energy is not the speed of the sound wave itself. The particles move at much faster rates than the wave itself, yet through them travelling faster they speed up the wave through providing a higher occurrence of collisions. It is this net transfer of energy through the particle collisions which forms the basis for the speed of the sound wave.

Would a wind blowing during your experiment have any effect on the value of speed of sound that you obtained? Explain your reasoning.

It is clear that wind blowing will affect sound waves. Through wind blowing, it compresses and decompresses the air molecules and therefore can change the apparent direction of the sound wave. As a result, sound may sound somewhat distorted from afar. However, in this experiment it is not likely that the wind factor would have any significant effect on the value of the speed of sound that was obtained. If the wind was travelling parallel to the direction of sound wave travel then this should have no effect at all on the results. Whether there is a head wind or a tail wind towards the pavilion, this would alter the speed for the 50 metres to get to the pavilion, yet once it is reflected back it is travelling through the same wind for the second medium, and this would balance out the effect. If there is initially a tail wind, it will be counteracted by a head wind for the second 50 metres, and vice-versa. However, if the direction of the wind was not parallel with the direction of the wave, this would have an effect on the value for the speed of sound of which we obtained. This is because no matter if the sound wave is travelling towards the pavilion, or is being reflected from it; the wind will still be blowing in the same direction, and pulling it offline slightly. This would mean that the sound wave would not be travelling in a straight line anymore, and in order to get back to the original position it would have to travel further. Thus, this should indicate a slower value for the speed of sound. In the experiment the direction of the wind was not measured or taken into consideration, so it is difficult to determine the effect it had on the value for the speed of sound.

A sonar device used by a fishing boat sends sound waves downwards into the water. A signal returns from a school of fish in 0.24 s. The speed of sound in sea water is 1500ms^{-1}.

(a) How far did the signal travel?

(b) How far are the fish from the boat?

(a) Given that $Speed = {}^{Distance}/_{Time}$, we are able to determine the total distance travelled if we know the other two values of speed and time. From the information given, the speed of sound in sea water is 1500ms^{-1} and the total time taken for the signal to return to the boat is 0.24 s. Therefore, through substituting the known values into the equation we are able to find the total distance travelled by the signal. Firstly, we must rearrange to make 'distance' the subject.

$$Distance = Speed \times Time$$
$$Distance = 1500 \times 0.24$$
$$Distance = 360m$$

Therefore, the total distance travelled by the signal is 360m.

(b) If the total distance travelled by the sound signal is 360 m, and the signal returns to the boat upon detecting the fish, this means that the fish are exactly half of the total distance travelled from the boat. If the total distance travelled is 360 m, the fish are therefore located 180 m away from the boat. i.e. the signal travels 180 m to get to the fish and 180 m more to get back to the boat, equalling the total distance travelled of 360 m.

In a thunderstorm you heard the thunder 5.0 s after you saw the lightning. Assuming that the speed of sound is 340ms^{-1}, how far away was the lightning produced?

Light travels much faster than that of sound. While sound in this case travels at 340ms^{-1}, light travels at$3.00 \times 10^8 ms^{-1}$. As light travels so much drastically faster, it is relatively insignificant upon doing these calculations, and we can assume that we see the light at the same time as it is produced (as it takes such a small amount of time to get to us). Therefore, in order to determine the distance in which the lightning is to us, we simply have to use the equation $Speed = {}^{Distance}/_{Time}$ and solve for Distance. We know the speed of sound is 340ms^{-1} and the time taken for the sound to get to us (assuming we see the light as it was produced) is 5 seconds. Therefore, through rearranging the formula,

$$Distance = Speed \times Time$$

$$Distance = 340 \times 5$$

$$Distance = 1.7km$$

Therefore, the lightning was produced 1.7 km away from where it was heard.

Further Analysis / Conclusion

In this experiment, if all factors were to align then hypothetically for a temperature of 0°C we would expect the speed of sound to be 331ms^{-1}. However, our two values for speed at 0°C were 292 and 358ms^{-1} respectively. It would be fair to say that these values are somewhat off what we would have hoped to expect, especially the first one. However, there are many factors that could explain this difference.

One realisation made was that when we were determining our first value for the speed of sound, when we were timing ten time intervals, the person timing it only timed ten hits of the metal. However, to produce ten time intervals, we would have had to time eleven hits of the metal, if the time began on the first hit. Again, delayed reaction time would also affect the results. This would explain why the speed of sound in this case was somewhat slower.

Another factor is that when we measured 50m from pavilion, we only measured 50 m from the front of the pavilion, and not from the back wall of it, where the sound is being reflected from. Therefore, the sound had to travel further than 100 metres to return to where it was created, and when calculated over 1000 m, this difference is only amplified further. This would result in the value for the speed of sound being slower than expected. This is indicative in the second value we recorded, which was done with minimal experimental errors yet was still slower.

As mentioned before, wind also could have played a part in the speed of sound, slowing it down if anything at all. As the wind would have blown the wave of its course, it no longer would have travelled in a straight line and therefore would have travelled more than 100 metres to return to its source. This would result in the speed of sound being slower.

Furthermore, it was not entirely clear whether the pavilion was the sole point of reflection for the sound wave. It was noted that the reflected sound almost sounded to be coming from a source not in the same direction as the pavilion. It is possible that the sound would have been reflected off nearby houses or trees, and therefore when the person hitting the metal was hitting it at the time of hearing the echo; he may have been hitting it for an echo which was faster or slower than the desired one, as it was not reflected off the pavilion.

After taking all these factors into consideration, it seems fairly reasonable that our value for the speed of sound, 358ms^{-1} was 27ms^{-1} slower than what should have been expected. The majority of all potential experimental errors would have slowed down the speed of sound, and so would not have counterbalanced one another to any extent. Through conducting this experiment, it is therefore clear that we successfully proved the speed of sound in air through the formula $Speed = {}^{Distance}/_{Time}$..