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Investigating the Doppler Effect when the Wave Source Moves in a Circular Path

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ABSTRACT

The commonly known Doppler Effect formula is used to calculate the observed frequency for an observer and a source that move relative to each other with constant velocity. However, this formula has a constraint: the relative movement between the source and the observer must be linear because if not, then due to change in direction, relative motion is not in constant velocity anymore. Additionally, when the source and observer move in relative linear motion, there is no change in the direction in which they approach or move away from each other and hence the wavelength of the observed wave is constant (and so is the observed frequency). However, when a wave source moves in circular motion, due to continuously changing velocity, there is a continuous change in the direction and hence the wavelength (and frequency) of the observed wave is always changing. Hence, to help observe this effect of Doppler Effect in circular motion better, this investigation was designed to focus on knowing how the change in the speed of the wave source when moving in a circular path affects the observed frequency.

Background Information

Doppler Effect is a common phenomenon in which a change in the pitch of a sound is observed when the wave source and the observer move relative to each other.

There are mainly two cases observed in Doppler Effect: when the wave source moves while the observer is stationary and when the observer moves while the wave source is stationary. In both these cases, the only factor that changes is the distance between the wave source and the observer. The change in this distance affects the number of wavefronts that reach the observer over time which is different from the number of wavefronts that the wave source emits over time. This change in the number of wave fronts that reach the observer over time marks the change in wavelength of the wave that reaches the observer and hence there is a change in the observed frequency.

It has been observed that when the observer moves towards a stationary wave source with a constant velocity, the observed frequency increases. However, if the observer moves away from the stationary wave source, the observed frequency decreases. Similarly, when a wave source advances towards a stationary observer with a constant velocity, the observed frequency increases while for a wave source moving away from the stationary observer at a constant velocity, the observed frequency decreases.

$$f' = f\left(\frac{c \pm v_o}{c \mp v_s}\right) : \text{Observed frequency (Doppler effect formula)}$$

For the formula shown above:

1. $v_0 -$ Velocity of observer, $v_s -$ Velocity of source
2. $c -$ Speed of sound in the experiment medium
3. $f' -$ Observed frequency, $f -$ Original frequency

Rationale for the Investigation

The Doppler Effect formula is used to calculate the observed frequency for an observer and a source that move relative to each other with constant velocity. However, this formula has a constraint: the relative movement between the source and the observer must be linear because if not, then due to change in direction, relative motion is not in constant velocity anymore.

I noticed the constraint of linear motion when an ambulance was standing beside my stationary car. Although the ambulance was also stationary, there was a change in the pitch of the siren due to the circular movement of the sound source in the siren. However, this change could not be noted by the known Doppler Effect formula because in circular motion the velocity of the moving source keeps changing unlike in linear motion (the formula condition).
Additionally, when the source and observer move in relative linear motion, there is no change in the direction in which they approach or move away from each other and hence the wavelength of the observed wave is constant. However, when a wave source moves in circular motion, due to continuously changing velocity, there is a continuous change in the direction and hence the wavelength of the observed wave is also always changing.

Hence, to help me observe this effect of Doppler Effect in circular motion better, I decided to investigate on how the change in the speed of the wave source when moving in a circular path affects the observed frequency.

Research Question

How does the change in the radius of the circular path (from 20cm to 60cm with an increment of 20cm each) in which a waves source travels, affect the observed frequency in Hz when the observer is stationary and placed outside the circular path of the wave source?

Hypothesis and Scientific Justification

"As the radius of the circular path is increased, the observed frequency for when the wave source approaches the observer will increase and when the wave source moves away from the observer, the observed frequency will decrease"

$$f' = f\left(\frac{c \pm v_o}{c \mp v_s}\right) : \text{Observed frequency (Doppler effect formula)}$$

With an increase in the radius of the circular path in which the wave source travels, there is an increase in the speed at which the wave source travels. According to the Doppler Effect formula, if the speed of the wave source is increased (due to increased radius), when the wave source approaches the observer, the $-v_s$ value will increase and hence the observed frequency will increase. Similarly, as the wave source moves away from the observer, the
$+v_s$ value will increase and hence the observed frequency will decrease.

"For the overall circular motion, when the wave source is approaching the observer, the observed frequency will increase continually and when it moves away from the observer, the observed frequency will decrease continually."
According to Doppler Effect in linear motion when the wave source moves away from the observer, the observed frequency decreases whereas when the wave source moves towards the observer, the observed frequency decreases.
Applying the same concept to the situation in which the wave source moves in circular motion, when the wave source is receding from the observer, the observed frequency will decrease but because this receding from the observer is at a continuously changing velocity, the decrease in the observed frequency will be continuous. Similarly, when the

wave source is approaching the observer, the observed frequency will increase continually due to continuous change in the velocity.

Independent Variable

Radius of the circular path followed by the wave source

According to the Doppler Effect formula, a change in the speed of the wave source affects the observed frequency and this is exactly what the investigation targets for when the wave source travels in a circular motion. In order to change the speed of the wave source, for this investigation the radius of the circular path followed by the wave source was changed. This is because, when the radius of the circular path is increased, the speed will increase since longer distance will have to be covered in the same time.

To change the speed of the wave source, 3 different values of the radius of the circular motion were chosen: 20cm, 40cm and 60cm. These values though are less, are appropriate because the less the radius, the more accurate readings will be obtained. The increment of $0.2m$ is appropriate because this value is enough to evaluate the difference in the observed frequency when the speed of the wave source is changed.

Dependent Variable

Observed frequency by the observer

Doppler Effect is the change in the observed frequency due to the relative motion between the wave source and the observer7. Hence to be able to investigate the Doppler Effect taking place during this investigation, the observed frequency must be noted.

For the experimental investigation, the observed frequency as the wave source moves in circular motion will be measured in hertz (Hz) using the app *"PhyPhox"*. This app can record rapidly changing frequencies and also gives a visual representation through graphs of the change in the frequency over time which is an additional advantage of using the app.

Another way in which the observed frequency when the radius of the wave source's circular path is changed can be measured is using the circular motion Doppler Effect formula that was theoretically derived by M.M.F. Saba and Rafael Rosa in their 2003 research paper "The Doppler Effect of a Sound Source Moving in a Circle". According to this formula:

$$f' = f\left[\frac{v_s}{v_s + \frac{2\pi R}{T}\cos\left(\frac{\pi t}{T}\right)}\right]$$

Controlled Variable

Quantity	Value	Why value must be controlled?
Emitted frequency	$1000\ Hz$	According to the Doppler effect formula, the emitted frequency has a major impact of the observed frequency and hence it has to be controlled
Distance between center of the circular path and the observer	$1m$	The distance at which the observer is placed does not affect the Doppler effect since regardless of the distance between the wave source and the observer, the number of wavefronts observed by the observer over time, will remain the same. However, it may increase external disturbances.

The position of the observer	The observer must be positioned on the same plane as the wave source	We live in a 3 dimensional world where the up and down dimensions are possible. Similarly how the distance between the wave source and the observer does not affect the observed frequency, the up and down dimensions doesn't matter. However, when the source and the observer are placed on the same plane, the disturbances in the wave source transmission decrease.
Speed of rotation of the wave source	30 rpm	While changing the radius of the circular path is one way to change the speed of the wave source, changing the rotational speed, is another way to change the speed of the wave source. Hence to avoid a huge overall uncalculated change in speed of the wave source, the speed of rotation of the wave source must be kept constant.

Table 1. All controlled variables involved in the investigation

Materials and Apparatus

Apparatus	Company	Uncertainty	Quantity	Application
Measuring tape	Faber Castle	±0.05 cm	1	To measure the distance between the observer and the center of the circular path and to measure the radius of the circular path
Phones	MI A2	±0.1 Hz	2	Wave Observer App: "PhyPhox"
	Galaxy M31			Wave Source App: "Physics Toolbox suite"
Ceiling Fan	Bajaj	-	1	To generate a rotational path for the wave source to move in.
Capacitor	-	-	2	To help reduce the speed of the ceiling fan by a significant amount and to reduce the rotational speed to 10 rpm
Masking Tape	-	-	1	To secure the wave source (phone 2) to one panel of the ceiling fan
Tachometer	Sigma Instruments	±0.1 cm	1	To measure the rotational speed of the fan
Camera	Cannon	-	1	To record the readings in relation to the position of the wave source in its circular path

Table 2. List of materials and apparatus used in the investigation

Preliminary experiment and pilot data

To gain a better understanding of what to expect during the actual experiment, a preliminary experiment was conducted. The wave source (phone with physics toolbox suite app) was attached to one of the plates of the ceiling fan, while the observer (phone with PhyPhox app) was placed stationary at level with the wave source attached to the ceiling fan.

The results of this experiment showed multiple peaks in the observed frequency during a single rotation around the circular path, which did not correspond with the expected result that in a single revolution, only one maximum and one minimum will be observed. This expectation might have been wrong, but later through close observation it was found that these unanticipated peaks occurred when the wave source was closing on a physical obstacle.

During this preliminary experiment, the place from where the sound was emitted for the wave was pointed outwards and hence the waves received by the observer were waves that were reflected by collisions with the walls. To overcome this problem, the wave source was adjusted in a way that the place from where the sound was emitted was directed downwards from where the sound waves could spread in all directions and therefore, the observer could detect the waves without the interference of an obstacle.

Experimental Setup

Figure 1. Experimental setup for the investigation

Experiment Methodology

In this investigation, either by using the formula or by physically performing the experiment information on how the change in radius of the circular motion affects the observed frequency can be gained.

$$f' = f\left[\frac{v_s}{v_s + \frac{2\pi R}{T}\cos\left(\frac{\pi t}{T}\right)}\right] : \text{Formula for doppler effect in circular motion}$$

Secondary data collection method:

1. In the given formula, input the following values:
   a. T: Time taken for one complete revolution $= 2s$

$$30 \text{ revolutions} ---- 60 \text{ seconds}$$
$$1 \text{ revolution} ----- x \text{ seconds}$$

$$30x = 60 \rightarrow x = 2 \text{ seconds}$$

   b. v_s: Speed of sound in air $= 340 \text{ ms}^{-1}$
   c. R: Radius of the circular path $= 20 \text{ cm} = 0.2 \text{ m}$
2. Consider t (time (s)) as the variable and graph the derived equation to see how over time (t) the observed frequency changes.
3. Repeat steps 1-2 for $R = 0.4$ and $R = 0.6$ that indicate a radius of 40 cm and 60 cm respectively

Primary data collection method:

1. "Physics Toolbox Suite" app's frequency generator (on the phone that will be the wave source) to 1000 Hz
2. Set the "PhyPhox" app's, Doppler effect category (on the phone that will be the wave observer) to the following:
   a. Base frequency:1000.0 Hz
   b. Time step: 50.0 ms
   c. Speed of sound: 340.0 ms^{-1}
3. Reduce the ceiling fan speed to 30 rpm, by adding two capacitors to the circuit of the ceiling fan.
4. Measure and mark 20 cm from the centre of the ceiling fan and attach the wave source to one panel of the ceiling fan at that mark.
5. To balance the weight, attach equally heavy objects to the remaining panels
6. Place the wave observer at a 1m distance from the centre of the fan.
7. To make sure that the wave observer is placed on the same level as the ceiling fan, stack some boxes to achieve the same height as the ceiling fan
8. Place the camera in such a position, that the readings of the wave observer and the placement of the wave source on the ceiling fan are visible.
9. Play the tone generator on the wave source and switch on the fan so that the wave source is now in motion.
10. Start the camera and then switch on the wave observer (phone) once the orbital speed of the wave source is set to 30 rpm.
11. After 5-6 complete rotations of the wave source, stop the camera recording and the wave observer, switch off the fan and pause the tone generator.
12. Export the results on the "PhyPhox" app of the wave observer and share the camera recording. Save all of these for further analysis.
13. Repeat steps 9-12 4 more times so that 5 different trails are available for each distance of wave source.
14. Repeat steps 1-13 for 40 cm and 60 cm radii of the circular motion of the wave source.

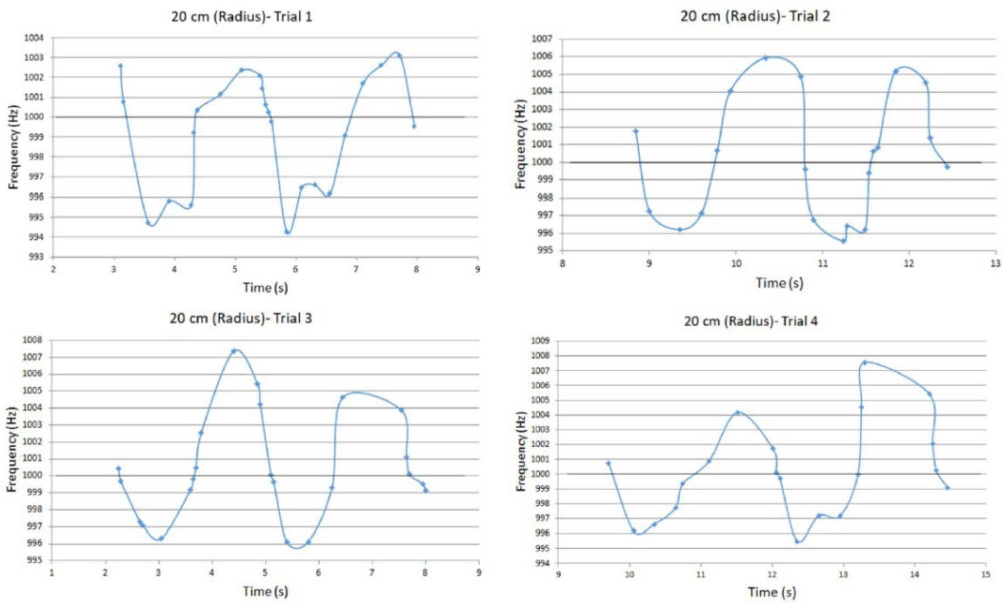
Risk Assessment

The experiment conducted for this investigation would not have been very risky had it been performed in a lab setting, however since due to the pandemic the experiment was conducted at home multiple risk factors were unintentionally involved. For example, since the entire experimental setup revolved around the ceiling fan, the experiment was conducted at an inadvisable height.

Additionally, as the radius of the circular path of the wave source was increased from 20 cm to 60 cm, more weights were added to other panels of the fan to prevent it from tilting. However, with additional weights, the fan was at risk of collapsing. To prevent this, readings were taken for only 3 different radius distances instead of 5 variations. There are some environmental risks as well that are involved in the investigation. For example, the online application used to record the observed frequency, must have contributed to an increase in the carbon footprint because the internet was being utilized. Similarly, since the ceiling fan had to be operated for the experiment, a lot of electricity was also used and this also contributed to the increase in the national carbon footprint. To avoid contributing to an increase in the carbon footprint, one must make sure that a minimum number of trials are required to get the required information through the experiment. By doing so fewer times the application will be used and also less electricity will be utilised in the process.

Experimental Data Collection

20 cm Radius of circular path (Graphical representation)[1]:

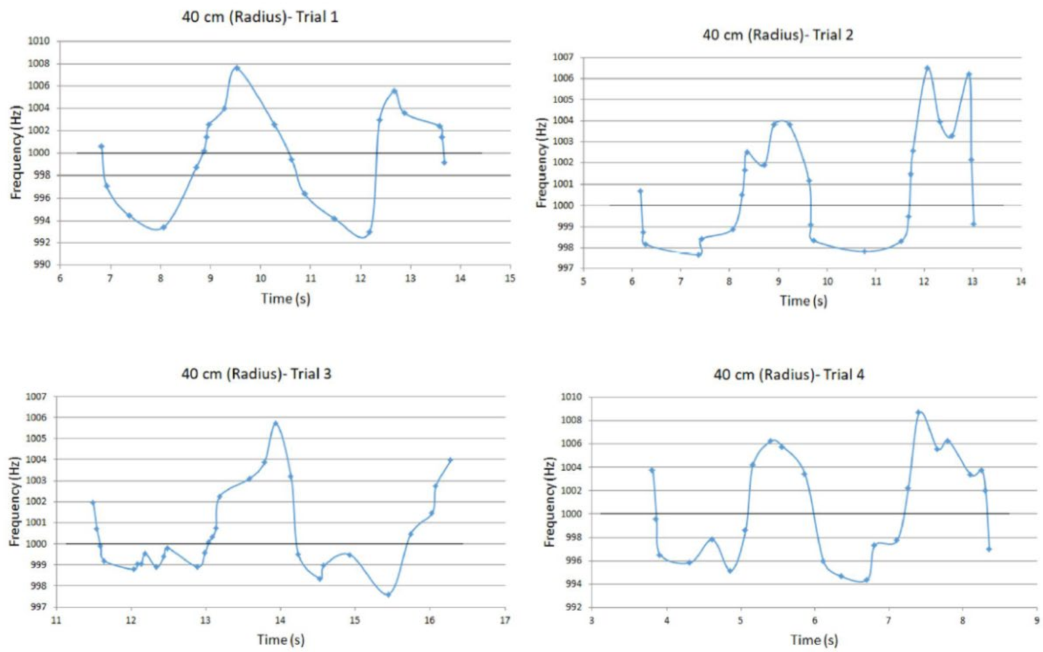


Graph 1. Graphical representation of observed frequency for all trials at 20cm radius of observer path

40 cm Radius of circular path (Graphical representation)[2]:

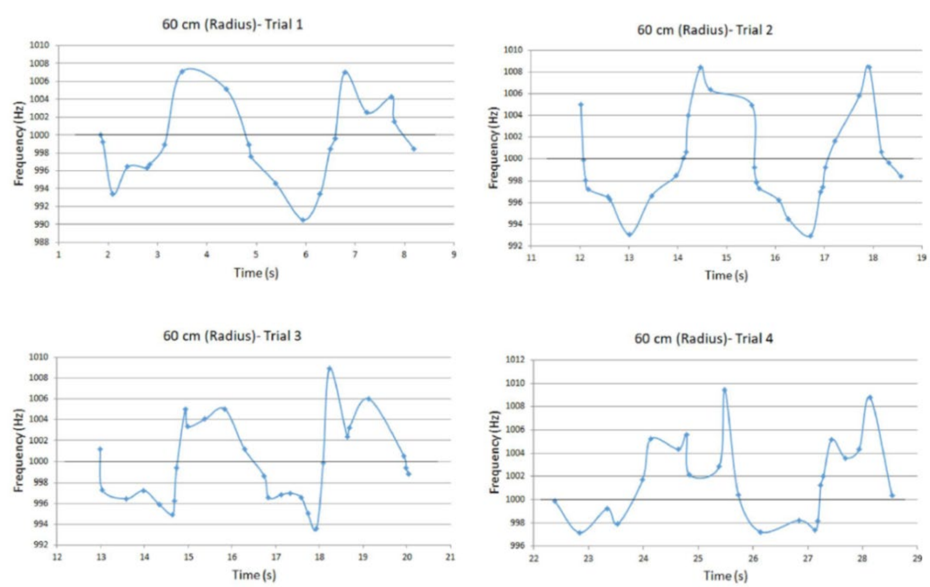
[1] Refer to Appendix 1

[2] Refer to Appendix 2



Graph 2. Graphical representation of observed frequency for all trials at 40cm radius of observer path

60 cm Radius of circular path (Graphical representation)[3]:



Graph 3. Graphical representation of observed frequency for all trials at 60cm radius of observer path

Average maximum and minimum frequencies

20 cm	Trial number	Maximum frequency (**Hz**)	Minimum frequency (**Hz**)
	Trial 1	1007.36	996.12

[3] Refer to Appendix 3

	Trial 2	1007.57	995.48
	Trial 3	1003.13	994.26
	Trial 4	1005.95	995.56
	Average value	1006.00 ± 2.22	995.36 ± 1.86

40 cm	Trial number	Maximum frequency (**Hz**)	Minimum frequency (**Hz**)
	Trial 1	1007.60	993.00
	Trial 2	1006.49	997.54
	Trial 3	1005.72	997.60
	Trial 4	1008.69	994.40
	Average value	1007.13 ± 1.49	995.64 ± 2.30

60 cm	Trial number	Maximum frequency (**Hz**)	Minimum frequency (**Hz**)
	Trial 1	1007.09	990.52
	Trial 2	1008.45	993.06
	Trial 3	1008.96	994.57
	Trial 4	1009.47	997.18
	Average value	1008.50 ± 1.19	$993.83 + 3.33$

Table 3. Average maximum and minimum frequencies for 20cm, 40cm and 60cm radius

To calculate the average maximum observed frequency of 20 cm radius:

$$\frac{1007.36 + 1007.57 + 1003.13 + 1005.95}{4} = 1006.00 \text{ Hz}$$

To calculate the uncertainty of the average maximum observed frequency of 20 cm radius:

$$\frac{\text{Minimum frequency} - \text{Minimum frequency}}{2} = \frac{1007.57 - 1003.13}{2} = 2.22$$

Similar calculations are performed for the average maximum/ minimum observed frequency and the uncertainty of these average observed frequencies

Average period of observed frequency graphs

Radius	Trial 1	Trial 2	Trial 3	Trial 4	Average period (**s**)
20 cm	2.39	2.19	3.04	2.70	2.58 ± 0.43
40 cm	3.46	2.66	2.55	1.94	2.86 ± 0.76
60 cm	3.05	2.66	3.74	3.35	3.20 ± 0.54

Table 4. Average period of observed frequency graph

The following is a sample calculation used to derive the above table. Similar calculations were performed for the average period of the observed frequency graph and their uncertainty.

To calculate the average period of the observed frequency graph for 20cm radius:

$$\frac{2.39 + 2.19 + 3.04 + 2.70}{4} = 2.58$$

To calculate the uncertainty of the observed frequency graph for 20cm radius:

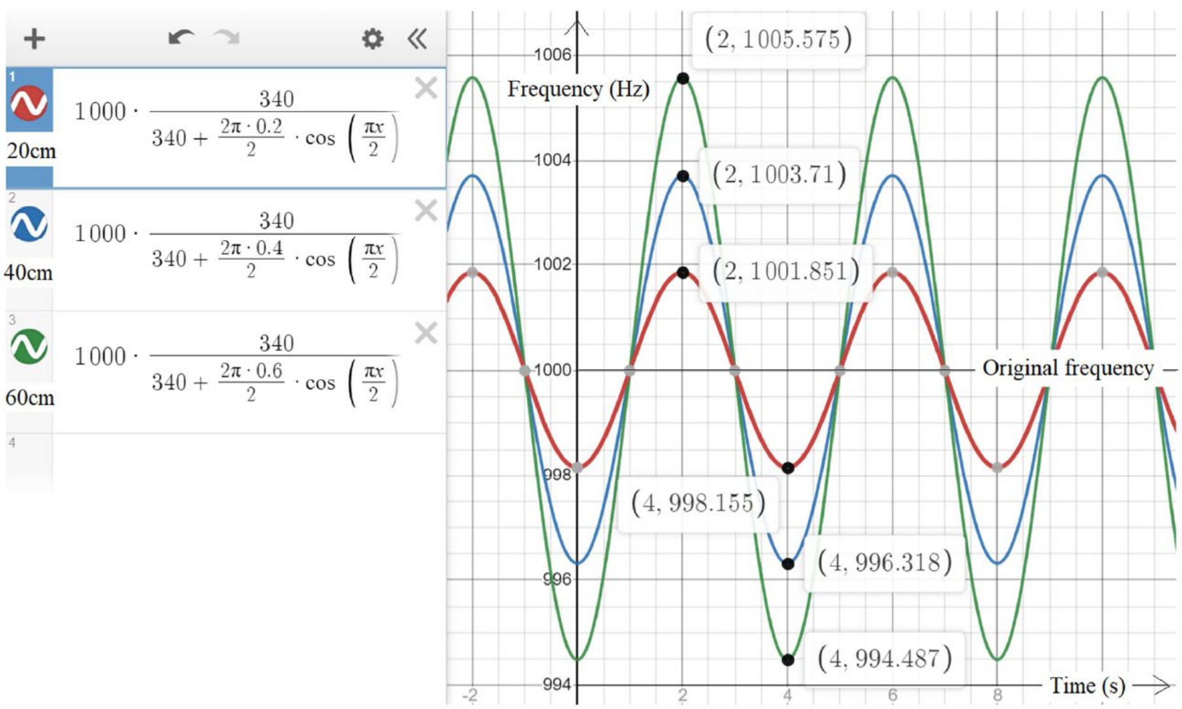
$$\frac{\text{Maximum period} - \text{Minimum period}}{2} = \frac{3.04 - 2.19}{2} = 0.43$$

Data collection using the formula for Doppler Effect in circular motion

By following the methodology for gaining data using the formula for Doppler Effect in circular motion, for each of the different radius values, we have the following graphs:

Radius	Corresponding formula	Important values from the graph
20cm	$1000 \times \left[\frac{340}{340 + \frac{2\pi \times 0.2}{2}\cos\left(\frac{\pi x}{2}\right)}\right]$	Maximum frequency: 1001.85 Hz Minimum frequency: 998.16 Hz Period of the observed frequency graph: 4s
40cm	$1000 \times \left[\frac{340}{340 + \frac{2\pi \times 0.4}{2}\cos\left(\frac{\pi x}{2}\right)}\right]$	Maximum frequency: 1003.71 Hz Minimum frequency: 996.32 Hz Period of the observed frequency graph: 4s
60cm	$1000 \times \left[\frac{340}{340 + \frac{2\pi \times 0.6}{2}\cos\left(\frac{\pi x}{2}\right)}\right]$	Maximum frequency: 1005.58 Hz Minimum frequency: 994.49 Hz Period of the observed frequency graph:4s

Table 5. Using the formula for Doppler Effect in circular motion



Graph 4. Graphical representation of the Doppler Effect in circular motion formula

Qualitative analysis of the investigation

While the graphs helped know how the observed frequency changed over time, only through visual analysis done through the primary data experiment, it was possible to know at what motion (receding or approaching) how the observed frequency changed.

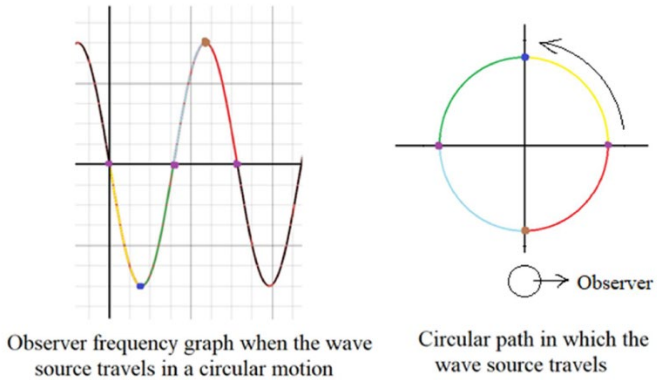


Figure 2. Diagrammatic representation of the relation between the circular motion of the wave source and the observed frequency graph

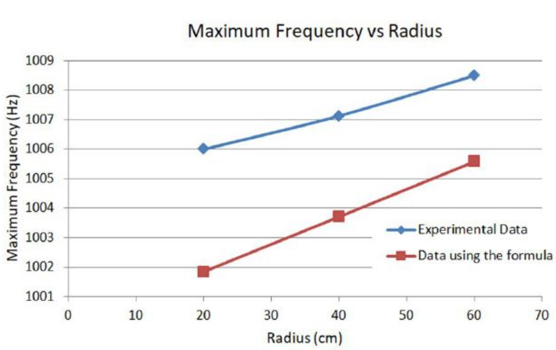
According to visual data, the following can be said about Doppler Effect in circular motion:

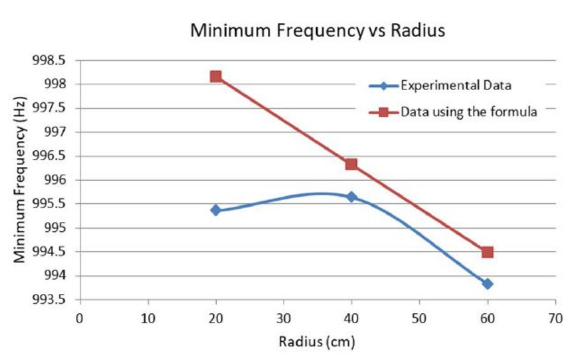
1. The maximum observed frequency is detected when the wave source is the closest to the observer
2. The minimum observed frequency is detected when the wave source is the farthest from the observer
3. When the wave source is receding, the observed frequency decreases
4. When the wave source is approaching, the observed frequency increases
5. The observed frequency is equal to the original frequency when the wave source is at mid-point on its half-circular path

Quantitative analysis of data collected

From the graphs derived from the experimental data as well as the graphs derived using the formula, it can be seen that the observed frequency varies in a periodic motion that when graphed gives a cosine function i.e. the observed frequency initially decreases as the wave source is moved away from the observer (receding) whereas it increases when the wave source travels closer to the observer (approaching).

Additionally, through the graphs derived from the formula, it can be seen that with increase in the radius of the circular path, there is an increase in the maximum frequency and a decrease in the minimum frequency. The same can be seen through the calculation of the average maximum and minimum frequencies of the experimental data, though there is a slight anomaly for the minimum frequency at 20 cm radius.





Graph 5. Trend in maximum and minimum frequencies as the radius changes

A final observation can be made regarding the period of the observed frequency graph. Though experimental data shows that there is a slight increase in the period of the observed frequency graph, according to theoretical data, the period the observed frequency graph remains the same. However, considering the uncertainties in the average period of the observed frequency graph calculated using experimental data, the values can be considered to be the same. Hence, it can be concluded that irrespective of the change in the radius of the circular path, the period of the observed frequency graph for each graph remains the same.

Data analysis against hypothesis and research question

The hypothesis had predicted: "As the radius of the circular path is increased, the observed frequency for when the wave source approaches the observer will increase and when the wave source moves away from the observer, the observed frequency will decrease".

This part of the hypothesis is supported by the experimental as well as the theoretical data. Although there is an anomaly in the data for the minimum observed frequency for 20 cm radius (which can be ignored due to high uncertainty), an overall trend can be seen. With increase in the radius of the circular path in which the wave source travels, the maximum observed frequency (due to approaching wave source) has increased while the minimum observed frequency (due to receding wave source) has decreased.

With increase in the radius of the circular path, the speed at which the wave source travels increases and hence, at the point of maximum frequency where the wave source approaches the observer, the observed frequency increases and at the point of minimum frequency, when the wave source was receding from the observer, the observed frequency decreases.

Another part of the hypothesis regarding the change in the radius stated: "For the overall circular motion, when the wave source is approaching the observer, the observed frequency will increase continually and when it moves away from the observer, the observed frequency will decrease continually". The data collected through experimental and theoretical exploration support the hypothesis. It can be seen that the observed frequency increases continually when the wave source moves towards the observer while the observed frequency is decreasing continually as the wave source moves away from the observer.

Similar to when wave source moves in circular motion, in linear motion when the wave source moves away from the observer, the observed frequency is less than the original frequency. However, unlike Doppler Effect in linear motion wherein although the wave source keeps moving away from the observer the observed frequency remains constant, for circular motion, as the wave source keeps moving away from the observer, the observed frequency keeps decreasing.

This happens because when in linear motion, although the wave source is moving away, the number of wavefronts that reach the observer in a given time remains constant, however, when in circular motion, the change in direction due to changing velocity causes fewer and fewer wavefronts to reach the observer over time and hence the frequency keeps decreasing as the wave source keeps receding from the observer in a circular path.
Similarly, for a wave source moving in circular motion, although like in linear motion the observed frequency is higher than the original frequency when the wave source approaches the observer, in circular motion, the observed frequency keeps increasing as the wave source continues approaching the observer. This is because as the wave source approaches the observer, more and more wavefronts reach the observer over a specified period hence the observed frequency keeps increasing.

Though not a part of the hypothesis, an important observation regarding the period the observed frequency graph was made. It was concluded that the period the observed frequency graph regardless of the change in radius remains constant. This happens because even though the radius is changed, the wave source completes one revolution around the circular path in the same time16. Hence the change in the maximum observed frequency (when closest to the observer) and the minimum observed frequency (when farthest from the observer) takes place over the same time regardless of the radius of the circular path.

From the qualitative analysis of the experimental data, it can be seen that unlike Doppler Effect in linear motion, in circular motion when the wave source is 1/4th distance from the closest point to the observer, the observed frequency is equal to the original frequency. From this, it can be concluded that when the wave source is 1/4th of its distance from the closest point to the observer, the number of wavefronts that the observer receives at this point is equal to the number of original wavefronts emitted by the wave source at that point.

Conclusion of the experiment

The impact of increasing the radius of the wave source's circular path on the observed frequency can be concluded as the following:

1. There is no change in the period the observed frequency graph
2. When the radius increases, the maximum observed frequency increases and the minimum observed frequency decreases.

The impact of circular motion of the wave source on the observed frequency can be concluded as:

1. When the wave source moves away from the observer, the observed frequency is decreasing as fewer wave-fronts reach the observer over time.
2. When the wave source is approaching the observer, the observed frequency is increasing as more wave-fronts reach the observer over time
3. The maximum observed frequency is achieved when the wave source approaches the closest point to the observer while the minimum observed frequency is achieved when the wave source recedes to the furthest point from the observer.
4. When the wave source is 1/4th distance away from the observer, the observed frequency is equal to the original frequency of the wave source.

Systematic errors in the experiment

Source of error	Explanation	Effect of this error	Improvements
Speed of the fan (High significance)	The additional weight on the ceiling fan also slowed down the speed of rotation by a little.	Since the speed of rotation was slowed down with additional weights, the time taken for the wave source to complete the rotation was longer. Hence even in the data it can be see that with increase in the radius there is a slight increase in the time period of the observed frequency graph	The speed of the fan must be adjusted to $30rpm$ after the weights have been added to the panels
Placing wave observer on the same plane as the wave source (Low significance)	Due to the addition of weights on the fan panels, the fan lowered down a little	Due to the ceiling fan lowering down, the observer and the wave source were not on the same plane for all readings. This may have affected the reading, but as mentioned before, distance does not play a very important role in the Doppler Effect.	Each time the weights were added to the fan, the height should be measured and the observer should be placed accordingly.

Table 6. Systematic errors in the experiment

Random errors in the experiment

Source of error	Explanation	Effect of this error	Improvements
Unpredicted oscillation (High significance)	The weights that were added to the fan to reverse the tilt caused by the wave source were not measured or carefully thought about.	Due to this, although the tilt was corrected, the fan was not accurately balanced. This imbalance could have caused an oscillation that could have affected the speed of the rotational motion.	Measure the weight of the wave source (phone) and add equal weights on the remaining panels of the ceiling fan
External sound disturbances (Low significance)	Even though an effort was made to reduce external sound disturbances by closing all windows, doors and switching off all fans, there were other disturbances such as birds chirping and wind blowing.	Although slight, there is a possibility that these disturbances were detected by the application because unless the observer was very sensitive to the surrounding sounds, it would not have been able to detect the change in frequency during Doppler Effect.	By performing this experiment in a sound-proof chamber or a place where external sound disturbances are minimum
Tape measure significance (Insignificant)	-	Since the measuring tape has an uncertainty of $\pm 0.05cm$, there is a possibility that the speed of the wave source was affected (due to the decrease in precision of the radius measuring).	No improvements possible

Table 7. Random errors during the experiment

Improvements and Extensions

Since this experiment was conducted in a pandemic and had a lot of constraints, multiple improvements can be made. Primarily, instead of using a ceiling fan, a rotating disk can be set up using a dc power motor to reduce errors caused by the ceiling fan and the weights added to stabilize it. Additionally, instead of using mobile applications to measure the change in the observed frequency, a multi-meter can be used to ensure accurate readings.

A major improvement to this project would be to increase the rotational speed of the rotational motion rather than to increase the radius to change the speed of the circular motion. By increasing the radius of the circular motion, un-intentionally, the wave source is brought closer to the observer since the distance from the centre of the circular path to the observer is kept constant. However, if instead the rotational speed is changed without changing the radius of the circular path of the wave source, the distance between the source and the observer would always remain constant and perhaps readings will be more accurate.

Additionally, it is known that Doppler Effect has two parts: moving source and moving observer. This experiment had only focused on the part of the moving source and not the moving observer. Hence, as an extension of this experiment, an investigation can be conducted to observe the Doppler Effect in circular motion when the observer moves instead of the source. This could be further extended to various cases wherein both, the observer and the source move in circular motions relative to each other. However, this may be too complicated to analyse in a simple setup.

Acknowledgments

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