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Investigating the reliability of using smartphone app and smartphone sensors in undergraduate laboratory experiments

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Abstract

In the present work we investigated a simple and interesting experiment in physics- Dopler effect- using smartphones to study the reliability of using the smartphone app 'Phyphox' as a laboratory tool to perform various experiments in Physics. Doppler effect is a fundamental principle in wave mechanics with numerous applications in various scientific fields. While our experiment modelled Doppler redshift with sound, it helps us visualize why astronomers observe redshifted light from galaxies. Though cosmological redshift and Doppler shift differ in their underlying physics, the understanding of Doppler shift plays a very significant role in the development and understanding of cosmological red shift, that is a key piece of observational evidence supporting the Big Bang theory. In our experimental setup, two smartphones and a laptop are taken to study the Doppler effect. One of the smartphones is mounted on a stand which acts as a stationary source of monochromatic sound and the other, with the app 'Phyphox' installed acts as a moving observer. A laptop is connected to the second phone to record the frequency change as the observer moves. The experimental results of observed Doppler effect are quantitatively compared with the theoretical predictions. The agreement of experimental data with the theoretical data indicates that the method adopted is valid and the app used is reliable.

Keywords: Doppler effect, Phyphox, monochromatic.

Introduction

In the contemporary trends in scientific education and research, smartphones have emerged as effective learning tool for theoretical knowledge as well as an experimental tool in acoustic and mechanical experiments. These pervasive devices, equipped with camera, high precision sensors and specialised apps have demonstrated numerous applications in physics education and laboratory experiments. This technological evolution marks a remarkable shift in pedagogical approaches in STEM education. The study of the Doppler effect using smartphone sensors has gained significant attention in recent physics education research. The Doppler effect is the change in frequency that occurs due to the relative motion between a source, emitting the wave and an observer [1,2]. Malik et al. (2020) [3] demonstrated the effectiveness of smartphone-based experiments by utilizing built-in microphone sensors to measure frequency shifts caused by relative motion between sound sources and observers. Their work achieved high accuracy, with error values as low as 0.04% for approaching sources and 0.1185% for receding sources, validating smartphones as viable tools for Doppler effect experiments.

Prior implementations of smartphone sensors in physics education include applications in kinematics [4], magnetic field measurements, and spectroscopy [5]. These studies collectively highlight the versatility of smartphones in replacing traditional lab equipment. Specifically for the Doppler effect, experiments have explored scenarios with moving sources, stationary observers, and mutual motion, with results aligning closely with theoretical predictions [6].

The work by Malik et al. [3] also identified limitations, such as sensor sensitivity and environmental noise, which can affect measurement precision. Despite these challenges, their findings support the broader adoption of smartphone-based experiments in educational settings, particularly where access to conventional lab equipment is limited. This approach not only enhances accessibility but also engages students by leveraging familiar technology to explore fundamental physics principles.

Doppler effect is an easily detectable effect and it occurs with all types of waves [7]. Though the underlying cause is different, it demonstrates a tangible analogy for understanding how wave stretching occurs- a key observational feature in both Doppler shift and cosmological redshift. It serves as a conceptual bridge to grasp what Hubble discovered: the spectra of the elements, coming from the distant extra galactic nebulae (now called galaxies), showed a redshift, which increased with the distance of the nebula (galaxy) from Earth [7,8].

The experimental setup used in our investigation consists of a stationary sound source, which emits pure sounds of three distinct frequencies viz. 800 Hz, 1000 Hz, and 1200 Hz [1], while a smartphone running the Phyphox [9] application served as the mobile detector [7]. By implementing both circular and linear motion patterns with the detector smartphone, we were able to systematically study how relative motion affects perceived frequency. This approach not only provides quantitative verification of the Doppler equations but also illustrates and validates the use of smartphone apps as useful tool for laboratory experiments.

Devices and Environment

Primary Devices:

i. Detector: One Smartphone running Phyphox to record frequency change.
ii. Source: Another smartphone emitting a fixed-frequency tone (800 Hz, 1000 Hz or 1200 Hz).

Secondary Devices:

i. A Laptop- used to view real-time results through Phyphox's remote access feature.
ii. Measuring Tape: Inch tape to measure the radius of circular motion path.

Environment:

i. Stable Wi-Fi Network: Enabled connection between Phyphox phone and laptop for data sharing.
ii. Quiet Room - Minimized background noise for accurate frequency measurements.
- Flat, open space for smooth circular/linear motion of the detector phone.

Setting up the experiment and collecting data

One of the smartphones which is kept stationary acts as the sound source, playing fixed frequencies (800Hz, 1000Hz and 1200Hz). Another phone with Phyphox installed is used to record the frequency shifts. A laptop is connected to Phyphox via remote access to monitor the live graphs.

Figure 1. Visualisation of experimental setup

For linear motion of the detector phone at a steady speed, the highest and lowest frequencies are recorded. The back-and-forth motion is repeated 3-4 times to ensure consistent readings. Readings are also taken for circular motion of the detector phone maintaining a fixed radius. Increase and decrease in frequency are noted as the phone moved towards and away from the source. The graph (Figure 2) shows peaks and dips corresponding to these shifts. The time intervals between shifts are noted to correlate with motion speed.

Data analysis

The collected data has been analysed using the Doppler formula [1]

$$f_0 = \frac{v \pm v_0}{v \pm v_s} f_s \qquad (1)$$

Fractional Doppler shift [7]

$$\frac{\Delta f}{f_s} = \frac{f_0 - f_s}{f_s} \qquad (2)$$

And the speed of the moving phone (observer) relative to the stationery source during each trial

$$V = C_s \cdot \frac{f_s - f_0}{f_s} \qquad (3)$$

The experiment in this paper demonstrates the principle of Doppler effect when the speed is significantly less than the speed of light.

While performing experiments for both the linear and circular motion, the data is monitored in real time using Phyphox's remote access feature connected to a laptop (Figure 2).

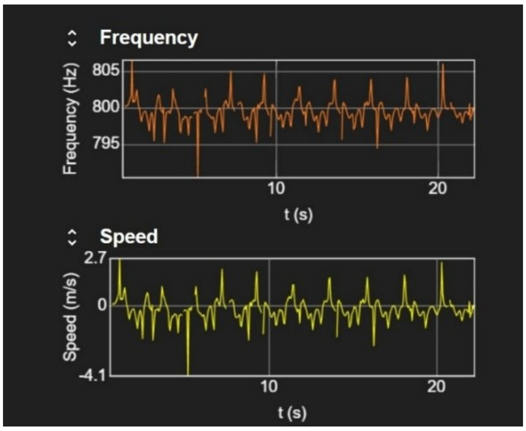

Figure 2. Phyphox real-time data

It is observed that the detected frequency increases when the detector phone moves toward the sound source and decreases when it moves away, confirming the Doppler effect.

A clear relationship is established between the speed of the detector phone and the magnitude of frequency shift—greater velocity resulted in a larger Doppler shift.

The experimentally observed values are compared with theoretical predictions and velocity (both calculated and observed) vs. frequency graphs and Fractional Doppler shift vs. velocity graphs are plotted to visualize and confirm the relationship.

Results and discussion

Doppler effect observation data and graphs when the observer is moving away from the stationary source [3] (Linear Motion of the observer) emitting 800 Hz, 1000 Hz, and 1200 Hz respectively, are represented in Table 1, 2, and 3 and Figure 3, 4 and 5.

Table 1. Observed and calculated data for 800Hz source frequency

Source frequency C_s (Hz)	Velocity of the source V_S (m/s)	Observed frequency f_O (Hz)	Observed velocity V_O (m/s)	Calculated velocity V (m/s)	Error (%)
800	0	795.31	2	1.99	0.5
800	0	792.21	3.34	3.31	0.89
800	0	791.96	3.44	3.41	0.87
800	0	791.50	3.65	3.61	1.09

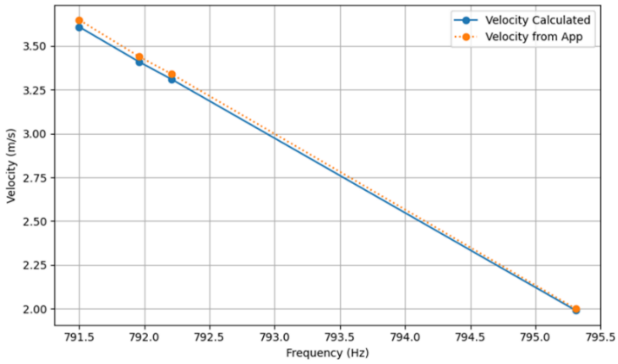

Figure 3. Frequency change when the observer is moving away from the stationary source (800 Hz)

Table 2. Observed and calculated data for 1000Hz source frequency

Source frequency C_s (Hz)	Velocity of the source V_S (m/s)	Observed requency f_O (Hz)	Observed velocity V_O (m/s)	Calculated velocity V (m/s)	Error (%)
1000	0	998.34	0.56	0.56	0
1000	0	996.21	1.29	1,28	0.77
1000	0	995.23	1.62	1.62	0
1000	0	993.09	2.36	2.34	0.85

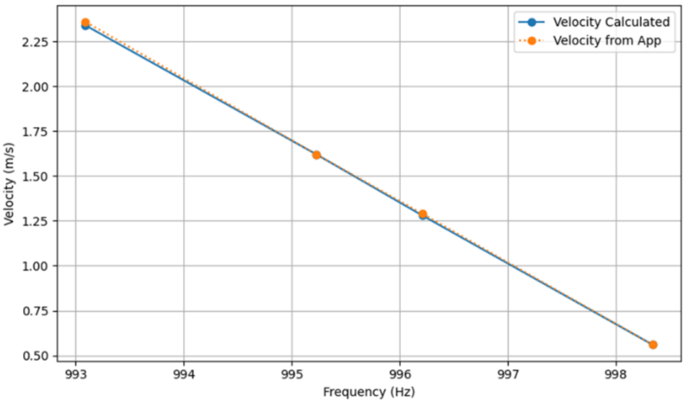

Figure 4. Frequency change when the observer is moving away from the stationary source (1000 Hz)

i. Table 3. Observed and calculated data for 1200Hz source frequency

Source frequency C_s (Hz)	Velocity of the source V_S (m/s)	Observed frequency f_O (Hz)	Observed velocity V_O (m/s)	Calculated velocity V (m/s)	Error (%)
1200	0	1193.27	1.91	1.90	0.52
1200	0	1192.60	2.10	2.09	0.48
1200	0	1190.93	2.58	2.56	0.77
1200	0	1190.81	2.62	2.60	0.76

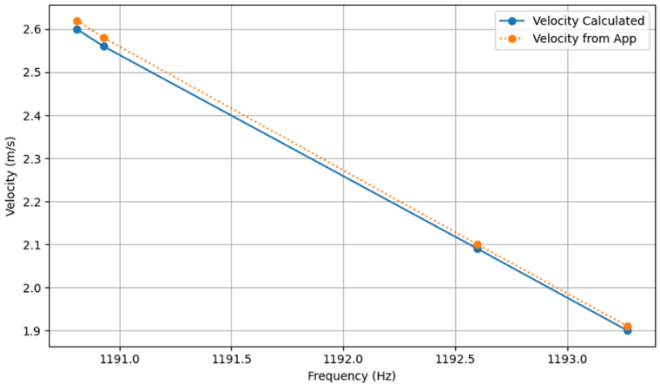

Figure 5. Frequency change when the observer is moving away from the stationary source (1200 Hz)

The figures 2, 3 and 4 clearly demonstrate that as we move the detector phone away from the sound source, the measured frequency consistently dropped. The faster the motion, the greater is the frequency drop [10]. At low speeds, the change was small, as expected, since the Doppler shift depends on how fast the observer moves relative to the speed of sound. Repeating the motion gave consistent results, confirming the reliability of the pattern.

For Circular motion of the observer, we have used two base frequencies- 800Hz and 1000Hz. In each frequency we have taken two different radii (20cm and 30cm) of the circular path along which the observer is moved. For two radii, similar results are observed. Doppler effect observation data and graphs for circular motion of the observer around the stationary sound source emitting 800 Hz and 1000 Hz respectively for radius 20 cm, are represented in Table 4 and 5 and Figure 6 and 7.

Table 4. Observed and calculated data for 800Hz source frequency (circular motion), taking radius= 20cm

Source frequency C_s (Hz)	Velocity of the Source V_S (m/s)	Observed Frequency f_O (Hz)	Observed velocity V_O (m/s)	Calculated velocity V (m/s)	Error (%)
800	0	794.97	2.14	2.137	0.14
800	0	795.23	2.039	2.02	0.93
800	0	795.90	1.72	1.74	1.16
800	0	796.76	1.37	1.37	0

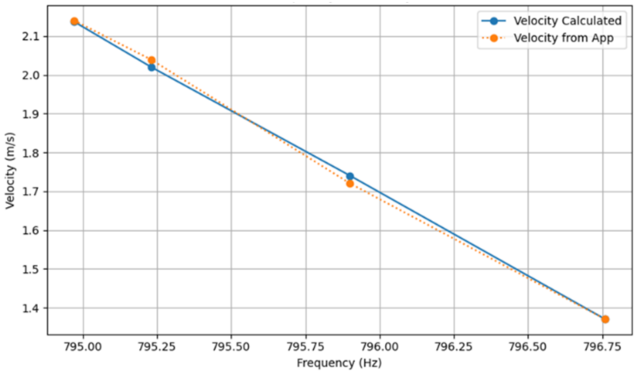

Figure 6. Frequency change for circular motion of the observer (800 Hz)

Table 5. Observed and calculated data for 1000Hz source frequency (circular motion), taking radius=20cm

Source frequency C_s (Hz)	Velocity of the source V_S (m/s)	Observed frequency f_O (Hz)	Observed velocity V_O (m/s)	Calculated velocity V (m/s)	Error (%)
1000	0	990.748	3.17	3.14	0.95
1000	0	993.990	2.05	2.04	0.49
1000	0	996.440	1.21	1.2104	0.03

1000	0	997.450	0.868	0.85	2.07

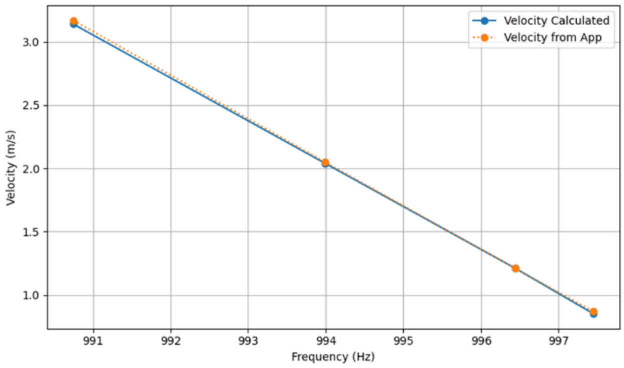

Figure 7. Frequency change for circular motion of the observer (1000 Hz)

During circular motion, we observed that the frequency shift varied depending on the direction of motion. The shift was greatest when the phone was moving directly away or toward the source. This created a repeating pattern of frequency peaks and drops as the phone rotated. The faster the rotation, the more pronounced the shifts became, clearly demonstrating how relative motion affects the observed frequency in a dynamic setup.

We plotted the fractional Doppler shift (Δf/fs) against the detector phone's velocity. The data showed a clear linear relationship: as the velocity increased (moving away from the source), the fractional frequency shift also increased in magnitude. Table 6 and Figure 8 represent recorded data and plot for Fractional Doppler shift Vs Velocity for Circular motion with source frequency - 1000Hz.

Table 6. Observed Fractional Doppler shift vs velocity data for circular motion (1000Hz), taking radius=20cm

Source frequency C_s (Hz)	Velocity of the source V_S (m/s)	Fractional Doppler Shift	Observed velocity V_O (m/s)	Calculated velocity V (m/s)
1000	0	0.0093	3.17	3.14
1000	0	0.00605	2.05	2.04
1000	0	0.0035	1.21	1.21
1000	0	0.0025	0.868	0.85

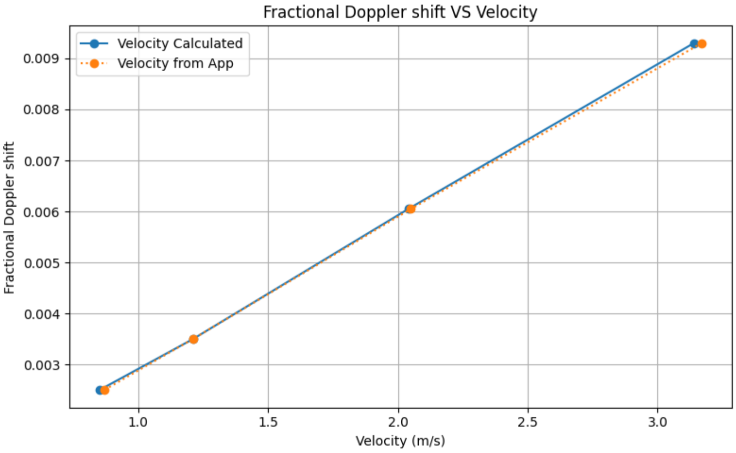

Figure 8. Graph of the fractional Doppler shift (Δf/fs) against the observed and calculated velocities.

The quantitative and graphical analysis directly supports the Doppler equation, Δf/fs = -v/c, where the shift is proportional to the observer's speed. This means that for a constant speed of sound, the faster the observer moves away, the more the frequency drops relative to the original. Although our experimental values closely followed the theoretical trend, we noticed minor deviations-likely due to real-world factors like motion inconsistency, app latency, and background noise.

Conclusion

For linear motion with receding observer, we observed that as the observer moved away from the stationary sound source, the measured frequency consistently decreased compared to the original emitted frequencies (800 Hz, 1000 Hz, and 1200 Hz). This confirmed the frequency shift phenomenon as predicted by the Doppler effect. The drop in frequency was more pronounced at higher velocities, meaning the faster the phone moved away, the greater the Doppler shift. At very low speeds, the frequency shift was minimal, which aligns with the Doppler equation since the shift depends on the ratio of relative velocity to the speed of sound.

In the rotational setup, we noticed that the frequency shift reached its maximum decrease when the phone was moving directly away from the source. As the phone moved along the circular path, the shift effect diminished when the direction of motion became more perpendicular to the source-observer line, since the radial velocity component decreased. The frequency shift followed a periodic pattern, peaking whenever the motion was purely receding.

The graph of Fractional Doppler Shift vs. Velocity showed a linear decrease in frequency with increasing receding velocity, matching the theoretical relationship:

$$\frac{\Delta f}{f_s} = -\frac{v}{c}$$

However, we noticed slight deviations between the expected and measured values, possibly due to measurement delays in the Phyphox app, background noise affecting frequency detection, non-uniform motion (e.g., acceleration/deceleration during movement).

For all three frequencies (800 Hz, 1000 Hz, 1200 Hz), the Doppler shift effect was clearly visible but the absolute frequency drop (Δf) was larger for higher frequencies. This is because Doppler shift is directly proportional to the initial frequency of the wave. So, a source emitting a high-frequency signal will experience a larger frequency shift when moving than a source emitting a low-frequency signal, even if they are moving at the same speed. Despite this, the fractional shift (Δf/fs) remained consistent for the same velocity, proving that the Doppler shift depends on the relative velocity, not the source frequency itself. Our graph of velocity versus Doppler shift illustrates how motion affects observed wave frequency, offering a conceptual insight into the wavelength stretching seen in cosmological redshift.

The present study demonstrates precision with Simple Tools. A universal principle is verified. Using only phones, we measured frequency shifts with <5% error, matching theoretical predictions, verifying the reliability and justifying the use of ‘Phyphox’ app in laboratory experiments in Physics and other disciplines.

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