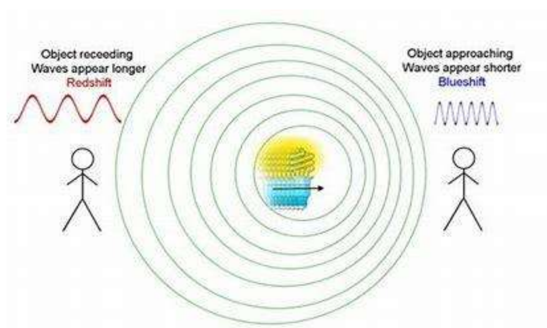
(Affiliated to C. B. S. E., New Delhi)
I Phase, J P Nagar,
Bengaluru-560078

THE OXFORD SENIOR SECONDARY SCHOOL

DOPPLER'S EFFECT



Submitted To: Mrs. Navya NR
PGT- PHYSICS

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Name: Ritwik Chawda
Class :XII 'A'
Roll No: 23
Subject and Code: PHYSICS [042]
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विद्या सर्वत्र शोभते

Estd. 1974

CERTIFICATE

This is to certify that the project entitled ‘ **DOPPLER’S EFFECT** ’ is a Bonafide work done by **Ritwik Chawda** of Class XII ‘A’, Session 2024-25 as prescribed by CBSE SSCE Examination 2025 and has been carried out under my supervision and guidance.

Roll Number	:
Date of the Examination	:
Signature of the Internal Examiner	:
Signature of the External Examiner	:
Signature of the Principal	:

AKNOWLEDGEMENT

I would like to express my gratitude to our beloved Principal Mrs. MALA BANERJEE and our Physics teacher Mrs. NAVYA NR, who gave me the golden opportunity to do this wonderful project on the topic Doppler's Effect which also helped me doing a lot of research and I came to know about so many new things. I am thankful to them.

Secondly, I would also like to thank my parents and friends who helped me a lot in finalizing this project within the limited time frame.

Last but not least, I would like to thank all those who helped towards the completion of this project.

Name of the student: Ritwik Chawda

Class : XII 'A'

INDEX

INTRODUCTION

Explain the Doppler Effect in simple terms. Include historical background (discovered by Christian Doppler in 1842) and its importance in physics and real-life applications. Mention how it applies to sound and light waves.

OBJECTIVE AND SCOPE

To study the Doppler Effect and demonstrate how the frequency of a sound wave changes with the relative motion of the source and observer.

HISTORY AND THEORY

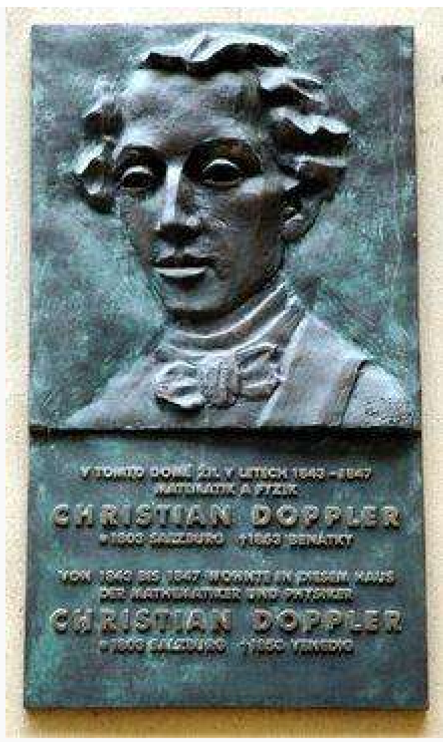
About Christian Doppler:

Christian Doppler

Born	29 November 1803 Salzburg, Austria
Died	17 March 1853 (aged 49) Venice, Italy
Nationality	Austria
Institutions	Prague Polytechnic Academy of Mines and Forests University of Vienna
Known for	Doppler effect

Christian Andreas Doppler (29 November 1803 – 17 March 1853) was an Austrian mathematician and physicist.

Christian Doppler was raised in Salzburg, Austria, the son of a stonemason. Doppler could not work in his father's business because of his generally weak physical condition. After completing high school Doppler studied philosophy in Salzburg and mathematics and physics at the *k. k. Polytechnisches Institut* (now Vienna University of Technology) where he worked as an assistant since 1829. In 1835 started to work at the *Prague Polytechnic* (now Czech Technical University), where he was appointed in 1841.



House in Prague in which Christian lived from 1843 to 1847

Only a year later, at the age of 38, Doppler gave a lecture to the Royal Bohemian Society of Sciences and subsequently published his most notable work, "Über das farbige Licht der Doppelsterne und einiger anderer Gestirne des Himmels" *(On the coloured light of the binary stars and some other stars of the heavens)*. There is a facsimile edition with an English translation by Alec Eden. In this work, Doppler postulated his principle (later coined the Doppler effect) that the observed frequency of a wave depends on the relative speed of the source and the observer, and he tried to use this concept for explaining the colour of binary stars. In Doppler's time in Prague as a professor he published over 50 articles on mathematics, physics and astronomy. In 1847 he left Prague for the professorship of mathematics, physics, and mechanics at the Academy of Mines and Forests (its successor is the present day University of Miskolc) in Selmecbánya (then Kingdom of Hungary, now Banská Štiavnica, Slovakia), and in 1849 he moved to Vienna.

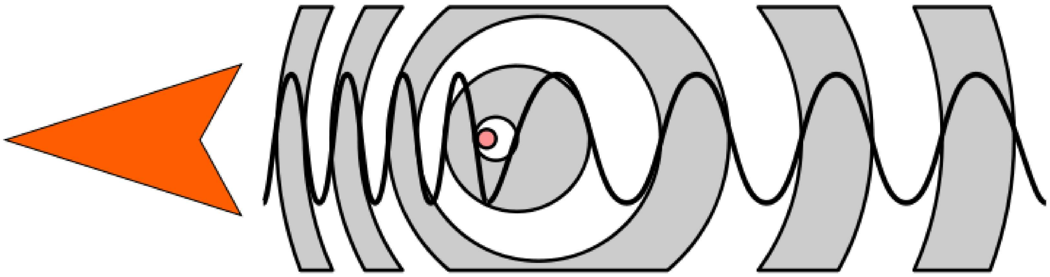
Doppler's research in Prague was interrupted by the revolutionary incidents of March 1848, when he fled to Vienna. There he was appointed head of the Institute for Experimental Physics at the University of Vienna in 1850. During his time there, Doppler, along withFranz Unger, played an influential role in the development of young Gregor Mendel, known as the founding father of genetics, who was a student at the University of Vienna from 1851 to 1853.

Doppler died on 18 March 1853 at age 49 from a pulmonary disease in Venice (also at that time part of the Austrian Empire). His tomb is just inside the entrance of the Venetian island cemetery of San Michele.

What is Doppler's Effect?

The **Doppler effect** (or **Doppler shift**), named after the Austrian physicist Christian Doppler, who proposed it in 1842 in Prague, is the change in frequency of a wave (or other periodic event) for an observer moving relative to its source. It is commonly heard when a vehicle sounding a siren or horn approaches, passes, and recedes from an observer. The received frequency is higher (compared to the emitted frequency) during the approach, it is identical at the instant of passing by, and it is lower during the recession.

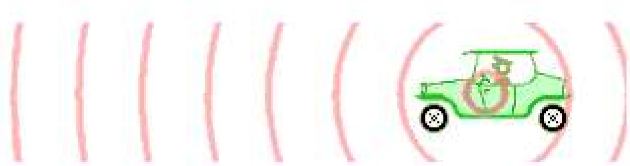
The relative changes in frequency can be explained as follows. When the source of the waves is moving toward the observer, each successive wave crest is emitted from a position closer to the observer than the previous wave. Therefore each wave takes slightly less time to reach the observer than the previous wave. Therefore the time between the arrival of successive wave crests at the observer is reduced, causing an increase in the frequency. While they are travelling, the distance between successive wave fronts is reduced; so the waves "bunch together". Conversely, if the source of waves is moving away from the observer, each wave is emitted from a position farther from the observer than the previous wave, so the arrival time between successive waves is increased, reducing the frequency. The distance between successive wave fronts is increased, so the waves "spread out".

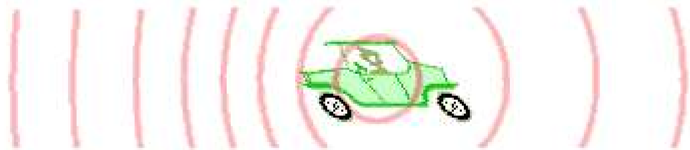


For waves that propagate in a medium, such as sound waves, the velocity of the observer and of the source are relative to the medium in which the waves are transmitted. The total Doppler effect may therefore result from motion of the source, motion of the observer, or motion of the medium. Each of these effects is analyzed separately. For waves which do not require a medium, such as light or gravity in general relativity, only the relative difference in velocity between the observer and the source needs to be considered.

How was Doppler's Effect Developed?

Doppler first proposed the effect in 1842 in his treatise "*Über das farbige Licht der Doppelsterne und einiger anderer Gestirne des Himmels*" (On the coloured light of the binary stars and some other stars of the heavens). The hypothesis was tested for sound waves by Buys Ballot in 1845. He confirmed that the sound's pitch was higher than the emitted frequency when the sound source approached him, and lower than the emitted frequency when the sound source receded from him. Hippolyte Fizeau discovered independently the same phenomenon on electromagnetic waves in 1848 (in France, the effect is sometimes called "effet Doppler-Fizeau" but that name was not adopted by the rest of the world as Fizeau's discovery was six years after Doppler's proposal). In Britain, John Scott Russell made an experimental study of the Doppler effect (1848).





This Illustrates how the Doppler effect causes a car engine or siren to sound higher in pitch when it is approaching than when it is receding. The pink circles are sound waves. When the car is moving to the left, each successive wave is emitted from a position further to the left than the previous wave. So for an observer in front *(left)* of the car, each wave takes slightly less time to reach him than the previous wave. The waves "bunch together", so the time between arrival of successive wavefronts is reduced, giving them a higher frequency. For an observer in back *(right)* of the car, each wave takes a slightly longer time to reach him than the previous wave. The waves "stretch apart", so the time between the arrival of successive wave-fronts is increased slightly, giving them a lower frequency.

General Formula of Doppler's Effect

In classical physics, where the speeds of source and the receiver relative to the medium

are lower than the velocity of waves in the medium, the relationship between observed frequency f and emitted frequency f_0 is given by:

$$f = \left(\frac{c + v_\text{r}}{c + v_\text{s}}\right) f_0$$

where

c is the velocity of waves in the medium;

v_r is the velocity of the receiver relative to the medium; positive if the receiver is moving towards the source (and negative in the other direction);

v_s is the velocity of the source relative to the medium; positive if the source is moving away from the receiver (and negative in the other direction).

The frequency is decreased if either is moving away from the other.

The above formula assumes that the source is either directly approaching or receding from the observer. If the source approaches the observer at an angle (but still with a constant velocity), the observed frequency that is first heard is higher than the object's emitted frequency. Thereafter, there is a monotonic decrease in the observed frequency as it gets closer to the observer, through equality when it is coming from a direction perpendicular to the relative motion (and was emitted at the point of closest approach; but when the wave is received, the source and observer will no longer be at their closest), and a continued monotonic decrease as it recedes from the observer. When the observer is very close to the path of the object, the transition from high to low frequency is very abrupt. When the observer is far from the path of the object, the transition from high to low frequency is gradual.

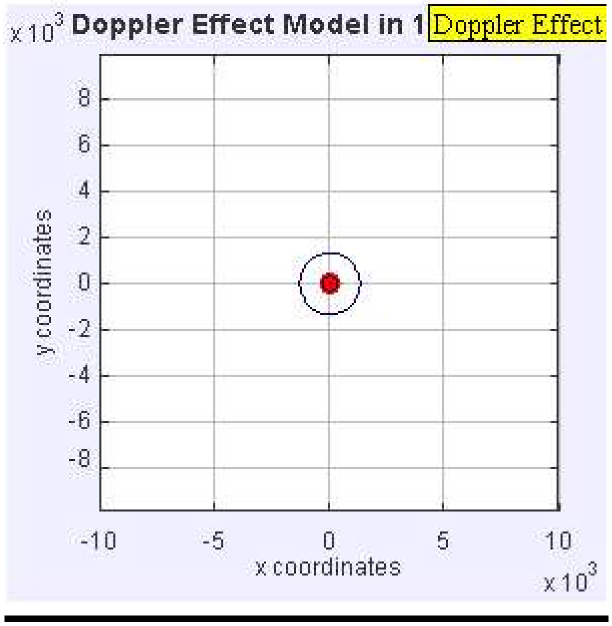
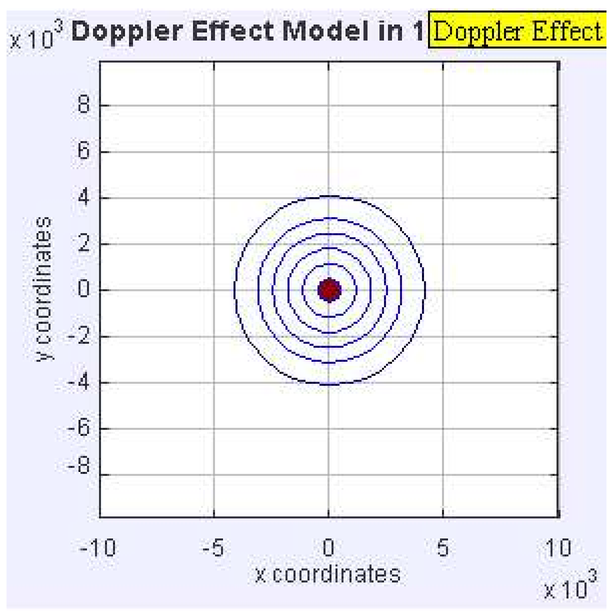
If the speeds v_s and v_r are small compared to the speed of the wave, the relationship between observed frequency f and emitted frequency f_0 is approximately

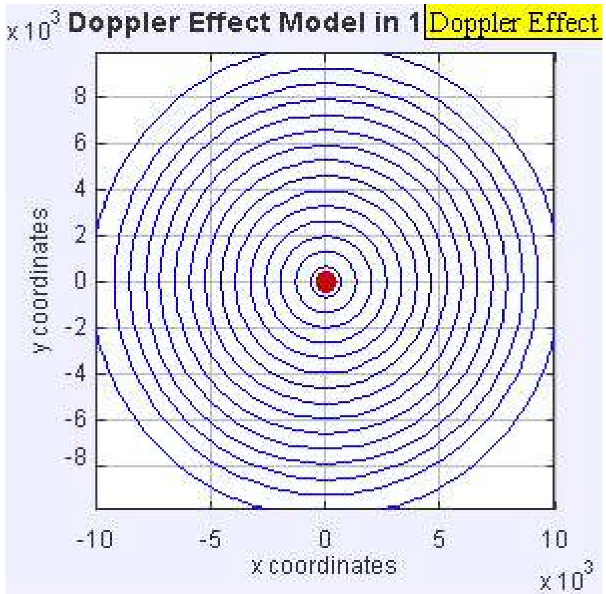
Observed frequency	**Change in frequency**
$f = \left(1 + \frac{\Delta v}{c}\right) f_0$	$\Delta f = \frac{\Delta v}{c} f_0$

where

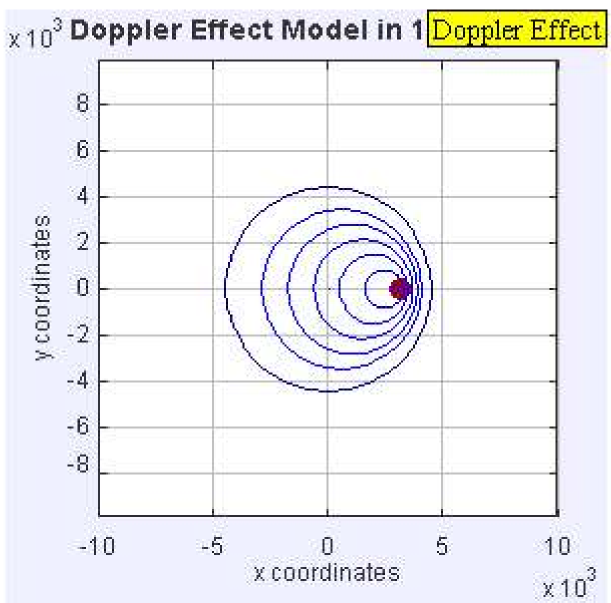
$$\Delta f = f - f_0$$

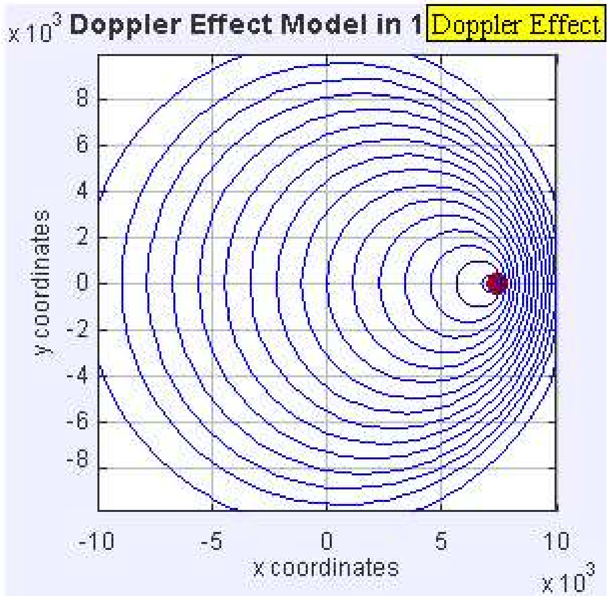
$\Delta v = v_r - v_s$ is the velocity of the receiver relative to the source: it is positive when the source and the receiver are moving towards each other.

x 10^3 Doppler Effect Model in 1 Doppler Effect 8 6 4 2 0 -2 -4 -6 -8 y coordinates -10 -5 0 5 10 x coordinates x 10^3
x 10^3 Doppler Effect Model in 1 Doppler Effect 8 6 4 2 0 -2 -4 -6 -8 y coordinates -10 -5 0 5 10 x coordinates x 10^3



Stationary sound source produces sound waves at a constant frequency f, and the wavefronts propagate symmetrically away from the source at a constant speed c. The distance between wavefronts is the wavelength. All observers will hear the same frequency, which will be equal to the actual frequency of the source where $f = f_0$





The same sound source is radiating sound waves at a constant frequency in the same medium. However, now the sound source is moving with a speed $v_s = 0.7\,c$ (Mach 0.7). Since the source is moving, the centre of each new wavefront is now slightly displaced to the right. As a result, the wavefronts begin to bunch up on the right side (in front of) and spread further apart on the left side (behind) of the source. An observer in front of the source will hear a higher frequency $f = c + 0/\boxed{c - 0.7c}\, f_0 = 3.33\, f_0$ and an observer behind the source will hear a lower frequency $f = c - 0/\boxed{c + 0.7c}\, f_0 = 0.59\, f_0$.

Analysis of Doppler's Effect

The frequency of the sounds that the source *emits* does not actually change. To understand what happens, consider the following analogy. Someone throws one ball every second in a man's direction. Assume that balls travel with constant velocity. If the thrower is stationary, the man will receive one ball every second. However, if the thrower is moving towards the man, he will receive balls more frequently because the balls will be less spaced out. The inverse is true if the thrower is moving away from the man. So it is actually the w*avelength* which is affected; as a consequence, the received frequency is also affected. It may also be said that the velocity of the wave remains constant whereas wavelength changes; hence frequency also changes.

With an observer stationary relative to the medium, if a moving source is emitting waves with an actual frequency f_0 (in this case, the wavelength is changed, the transmission velocity of the wave keeps constant — note that the *transmission velocity* of the wave does not depend on the *velocity of the source*), then the observer detects waves with a frequency f given by

$$f = \left(\frac{c}{c + v_s}\right) f_0$$

A similar analysis for a moving *observer* and a stationary source (in this case, the wavelength keeps constant, but due to the motion, the rate at which the observer receives waves — and hence the *transmission velocity* of the wave [with respect to the observer] — is changed) yields the observed frequency:

$$f = \left(\frac{c + v_r}{c}\right) f_0$$

These can be generalized into the equation that was presented in the previous section.

$$f = \left(\frac{c + v_r}{c + v_s}\right) f_0$$

An interesting effect was predicted by Lord Rayleigh in his classic book on sound: if the source is moving at twice the speed of sound, a musical piece emitted by that source would be heard in correct time and tune, but *backwards*.

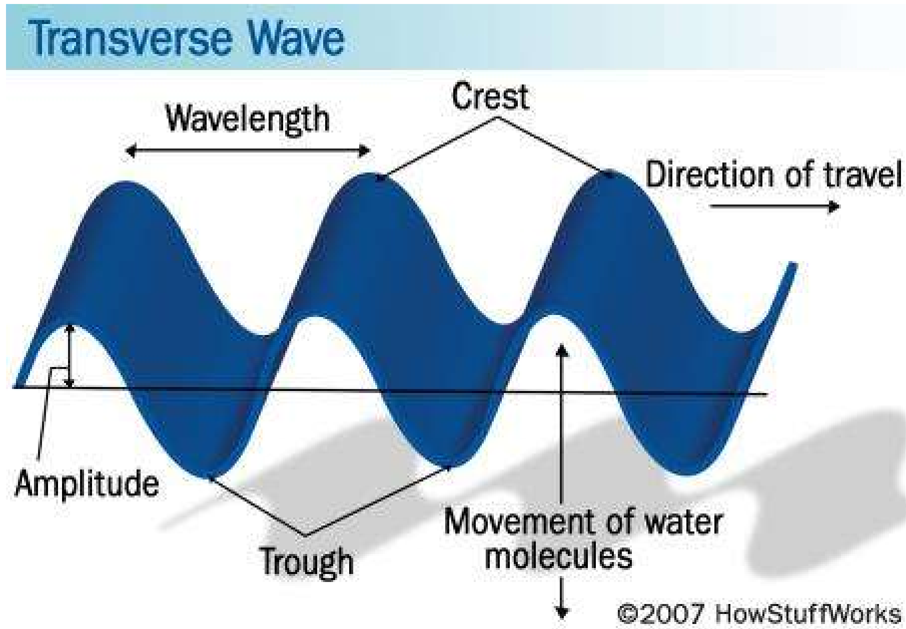
How Doppler's Effect Works

Christoph Hendrik Diederik Buys Ballot conducted this very experiment in 1845. He assembled a group of horn players and placed them in an open cart attached to a locomotive. Then he had the engineer start up the locomotive so it could carry the cart, complete with the horn players, back and forth along the track. As they were being pulled, the musicians played a single note on their horns. Ballot stationed himself beside the track and listened carefully, both as the train approached and receded. And the notes he heard were different than the notes being played by the musicians.

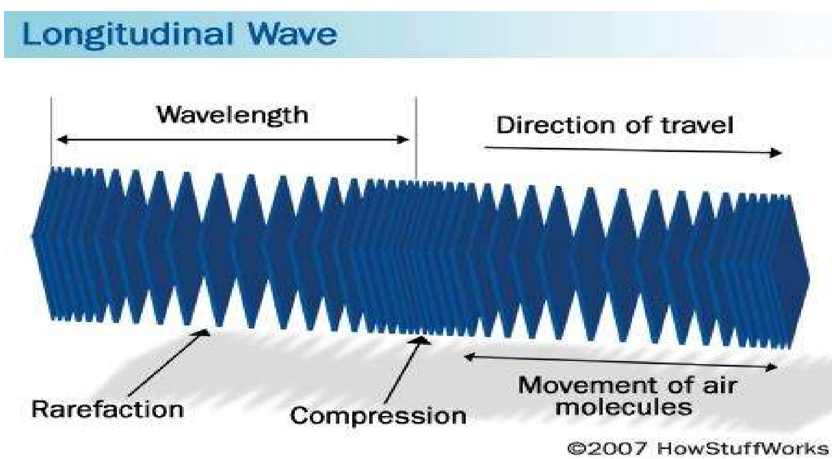
Although unusual, Ballot's experiment demonstrated clearly one of the most important wave phenomena known to scientists. The phenomenon is called the **Doppler effect** after Austrian mathematician Christian Johann Doppler, who first predicted this odd behavior of sound in 1842. Today, scientists know that the Doppler effect applies to all types of waves, including water, sound and light. They also have a good idea why the Doppler effect occurs. And they've incorporated its principles into a variety of useful tools and gadgets.

Doppler's Effect makes use of two types of Waves:

1) Transverse Wave



2) Longitudanal Waves



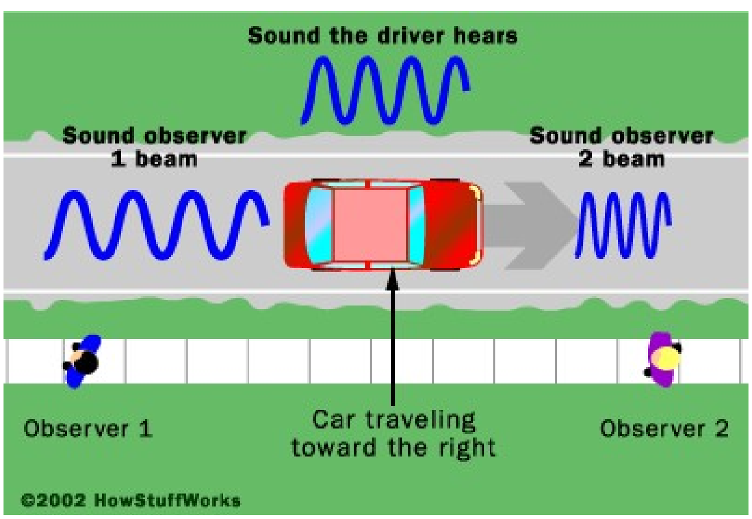
When most people think of waves, they think of water waves. But light and sound also travel as waves. A light wave, like a water wave, is an example of a **transverse wave**, which causes a disturbance in a medium perpendicular to the direction of the advancing wave.

The distance between any two crests (or any two troughs) is the **wavelength**, while the height of a crest (or the depth of a trough) is the **amplitude**. **Frequency** refers to the number of crests or troughs that pass a fixed point per second. The frequency of a light wave determines its color, with higher frequencies producing colors on the blue and violet end of the spectrum and lower frequencies producing colors on the red end of the spectrum.

Sound waves are not transverse waves. They are **longitudinal waves**, created by some type of mechanical vibration that produces a series of compressions and rarefactions in a medium. Take a woodwind instrument, such as a clarinet. When you blow into a clarinet, a thin reed begins to vibrate. The vibrating reed first pushes against air molecules (the medium), then pulls away. This results in an area where all of the air molecules are pressed together and, right beside it, an area where air molecules are spread far apart. As these compressions and rarefactions propagate from one point to another, they form a longitudinal wave, with the disturbance in the medium moving in the same direction as the wave itself.

If you study the diagram of the longitudanal wave above, you'll see that longitudinal waves have the same basic characteristics as transverse waves. They have wavelength (the distance between two compressions), amplitude (the amount the medium is compressed) and frequency (the number of compressions that pass a fixed point per second). The amplitude of a sound wave determines its **intensity**, or loudness. The frequency of a sound wave determines its pitch, with higher frequencies producing higher notes. For example, the open sixth string of a guitar vibrates at a frequency of 82.407 hertz (cycles per second) and produces a lower pitch. The open first string vibrates at a frequency of 329.63 hertz and produces a higher pitch.

Doppler's Effect also makes use of Wave Frequency:



Consider a source that creates waves in water at a certain frequency. This source produces a series of wave fronts, with each moving outward in a sphere centered on the source. The distance between wave crests -- the wavelength -- will remain the same all the way around the sphere. An observer in front of the wave source will see the waves equally spaced as they approach. So will an observer located behind the wave source.

Now let's consider a situation where the source is not stationary, but is moving to the right as it produces waves. Because the source is moving, it begins to catch up to the wave crests on one side while it moves away from the crests on the opposite side. An observer located in front of the source will see the crests all bunched up. An observer located behind the source will see the waves all stretched out. Remember, the frequency equals the number of waves that pass a specific point per second, so the observer in front actually sees a higher frequency than the observer in back of the source.

The scenario above describes waves formed in water, but it also applies to sound waves and light waves. Sound waves are heard, not seen, so the observer will hear the bunched-up waves as a higher-pitched sound, the stretched-out waves as a lower-pitched sound. For example, consider a car traveling down a highway between two observers, as shown below. The roar of the engine and friction between the tires and the road surface create a noise -- vroom -- that can be heard by both observers and by the driver.

To the driver, this noise will not change. But the observer located in front of the car will hear a higher-pitched noise. Why? Because the sound waves compress as the vehicle approaches the observer located in front. This increases the frequency of the wave, and the pitch of the vroom rises. The observer located behind the car will hear a lower-pitched noise because the sound waves stretch out as the car recedes. This decreases the frequency of the wave, and the pitch of the vroom falls.

Light waves are perceived as color, so the observer will sense the bunched-up waves as a bluer color, the stretched-out waves as a redder color. For example, consider an astronomer observing a galaxy through atelescope. If the galaxy is rushing toward Earth, the light waves it produces will bunch up as it approaches the astronomer's telescope. This increases the frequency of the wave, which shifts the colors of its spectral output toward the blue. If the galaxy is rushing away from Earth, the light waves it produces will spread apart as it recedes from the astronomer's telescope. This decreases the frequency of the wave, which shifts the colors of its spectral output toward the red.

As you can imagine, astronomers routinely take advantage of the Doppler effect to measure the speed at which planets, stars and galaxies are moving. But its usefulness isn't limited to outer space. Doppler's discovery is integral to several applications right here on Earth.

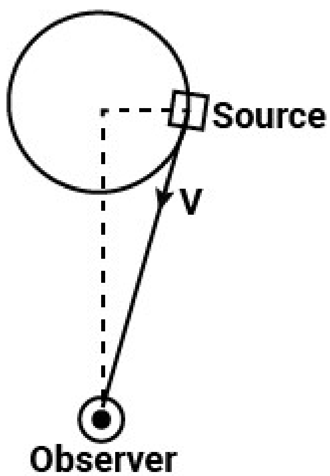
EXPERIMENT

To demonstrate doppler's effect by the help of a buzzer. As we swing the string in a circular motion we observe change in the frequency of the sound produced by the buzzer as it comes closer to us as well as when it moves away from us.

Procedure

1. Attach a buzzer to a 9V battery.
2. Attach this setup to a string firmly.
3. Now rotate it in a circular motion.
4. You would now be able to feel change in frequency of sound.
5. The frequency increases as the source comes near to the observer.
6. The frequency decreases as it moves away from the observer.
7. Thus, explaining doppler's effect.

Buzzer Setup


Source
V
Observer

SCOPE AND CONCLUSION

Practical Applications of Doppler's Effect

Sirens

The siren on a passing emergency vehicle will start out higher than its stationary pitch, slide down as it passes, and continue lower than its stationary pitch as it recedes from the observer. Astronomer John Dobson explained the effect thus:

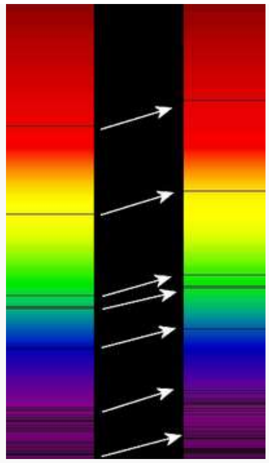
"The reason the siren slides is because it doesn't hit you."

In other words, if the siren approached the observer directly, the pitch would remain constant until the vehicle hit him, and then immediately jump to a new lower pitch. Because the vehicle passes by the observer, the radial velocity does not remain constant, but instead varies as a function of the angle between his line of sight and the siren's velocity:

$$v_{\text{radial}} = v_{\text{s}} \cdot \cos\theta$$

where θ is the angle between the object's forward velocity and the line of sight from the object to the observer.

Astronomy



Redshift of spectral lines in theoptical spectrum of a supercluster of distant galaxies (right), as compared to that of the Sun (left)

The Doppler effect for electromagnetic waves such as light is of great use in astronomy and results in either a so-called redshift orblueshift. It has been used to measure the speed at which stars and galaxies are approaching or receding from us, that is, the radial velocity. This is used to detect if an apparently single star is, in reality, a close binary and even to measure the rotational speed of stars and galaxies.

The use of the Doppler effect for light in astronomy depends on our knowledge that the spectra of stars are not continuous. They exhibitabsorption lines at well defined frequencies that are correlated with the energies required to excite electrons in various elements from one level to another. The Doppler effect is recognizable in the fact that the absorption lines are not always at the frequencies that are obtained from the spectrum of a stationary light source. Since blue light has a higher frequency than red light, the spectral lines of an approaching astronomical light source exhibit a blueshift and those of a receding astronomical light source exhibit a redshift.

Among the nearby stars, the largest radial velocities with respect to the Sun are +308 km/s (BD-15°4041, also known as LHS 52, 81.7 light-years away) and -260 km/s (Woolley 9722, also known as Wolf 1106 and LHS 64, 78.2 light-years away). Positive radial velocity means the star is receding from the Sun, negative that it is approaching.

Temperature measurement

Another use of the Doppler effect, which is found mostly in plasma physics and astronomy, is the estimation of the temperature of a gas (or ion temperature in a plasma) which is emitting a spectral line. Due to the thermal motion of the emitters, the light emitted by each particle can be slightly red- or blue-shifted, and the net effect is a broadening of the line. This line shape is called a Doppler profile and the width of the line is proportional to the square root of the temperature of the emitting species, allowing a spectral line (with the width dominated by the Doppler broadening) to be used to infer the temperature.

Radar

The Doppler effect is used in some types of radar, to measure the velocity of detected objects. A radar beam is fired at a moving target — e.g. a motor car, as police use radar to detect speeding motorists — as it approaches or recedes from the radar source. Each successive radar wave has to travel farther to reach the car, before being reflected and re-detected near the source. As each wave has to move farther, the gap between each wave increases, increasing the wavelength. In some situations, the radar beam is fired at the moving car as it approaches, in which case each successive wave travels a lesser distance, decreasing the wavelength. In either situation, calculations from the Doppler effect accurately determine the car's velocity. Moreover, the proximity fuze, developed during World War II, relies upon Doppler radar to detonate explosives at the correct time, height, distance, etc.

Flow measurement

Instruments such as the laser Doppler velocimeter (LDV), and acoustic Doppler velocimeter (ADV) have been developed to measurevelocities in a fluid flow. The LDV emits a light beam and the ADV emits an ultrasonic acoustic burst, and measure the Doppler shift in wavelengths of reflections from particles moving with the flow. The actual flow is computed as a function of the water velocity and phase. This technique allows non-intrusive flow measurements, at high precision and high frequency.

Satellite communication

Fast moving satellites can have a Doppler shift of dozens of kilohertz relative to a ground station. The speed, thus magnitude of Doppler effect, changes due to earth curvature. Dynamic Doppler compensation, where the frequency of a signal is changed multiple times during transmission, is used so the satellite receives a constant frequency signal.

Underwater acoustics

In military applications the Doppler shift of a target is used to ascertain the speed of a submarine using both passive and active sonar systems. As a submarine passes by a passive sonobuoy, the stable frequencies undergo a Doppler shift, and the speed and range from the sonobuoy can be calculated. If the sonar system is mounted on a moving ship or another submarine, then the relative velocity can be calculated.

Vibration measurement

A laser Doppler vibrometer (LDV) is a non-contact method for measuring vibration. The laser beam from the LDV is directed at the surface of interest, and the vibration amplitude and frequency are extracted from the Doppler shift of the laser beam frequency due to the motion of the surface.

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