Nature & Science
November 2025, Vol. 7, Issue 11, pp. 28–32
DOI: https://doi.org/10.36719/2707-1146/62/28-32

The Nature of the Doppler Effect

Gunay Dadashzade

Abstract. *This text explains the physical nature of the Doppler effect, its classical and relativistic manifestations, and its practical applications in science. The longitudinal and transverse effects, their differences, and experimental confirmations are discussed. The historical milestones of the discovery and confirmation of the effect are described, as well as its significance for astrophysics and the theory of relativity. The Doppler effect is a change in the frequency and wavelength of waves recorded by a receiver due to the movement of the source and/or receiver.*

Keywords: *electromagnetic, Doppler effect, partticles, waves, observation*

Introduction

One of the most interesting, unusual, and optically beautiful phenomena, yet underrepresented in school physics, is the Doppler effect. The Doppler effect describes the change in wave frequency due to the relative motion of a source or observer. A study of popular science literature and online sources revealed that this effect plays a key role in radio engineering, medical devices, and optical systems. In today's world of progressive technological advancement, this effect is used not only to optimize existing technologies but also to create new, more efficient engineering systems. Therefore, I believe that studying the Doppler effect is an important and relevant research topic. The effect is most clearly evident when a car with a siren passes by: the pitch increases as it approaches, and decreases as it recedes. For sound waves, motion relative to the medium is taken into account, while for light, only the relative motion of the source and receiver is considered. The effect was first described by Christian Doppler in 1842.

Methods

The relativistic Doppler effect is explained by both the classical change in frequency and time dilation. At low speeds, the relativistic formula coincides with the classical one. The longitudinal Doppler effect (motion along the line of observation) is used in astrophysics to analyze the motion of celestial bodies based on the shift of spectral lines. The transverse Doppler effect (motion perpendicular to the line of observation) is a purely relativistic phenomenon, confirmed by the experiments of Ives and Stilwell in 1938, providing evidence of time dilation in moving frames of reference (Yavorsky, 1981, pp. 43–47).

This phenomenon is characteristic of all types of waves and particle flows, but Doppler arrived at this discovery while studying the properties of sound waves. Indeed, the Doppler effect is most often encountered in acoustics. It is known that the frequency of sound vibrations is perceived by the human ear as pitch (Arkhangelsky, 1975, pp. 57–59).

Azerbaijan State Pedagogical College, Baku, Azerbaijan
E-mail: gunay_dadaszade@mail.ru
Received: 30 July 2025; Accepted: 28 October 2025; Published online: 25 November 2025

Doppler discovered that as a sound source approaches an observer (the receiver of the sound waves), the pitch of the sound will appear higher than if the same source were emitting the sound at rest. Conversely, as the sound source moves away from the observer, the pitch of the sound waves will decrease. One of the most widely known applications is determining the speed of moving objects using velocity sensors. Radar signals are reflected by vehicles and returned. The frequency shift with which the signals return is directly related to the vehicle's speed. By comparing the speed and frequency change, speed can be calculated (Gorokhov, 1990, pp. 94−97).

Findings and Discussion

The Doppler effect is widely used in medicine. It underlies the operation of ultrasound diagnostic devices. There is a separate ultrasound technique called Dopplerography. The Doppler effect is also used in optics, acoustics, electronics, astronomy, and radar. The discovery of the Doppler effect played a crucial role in the development of modern physics. One of the confirmations of the Big Bang theory is based on this effect. How are the Doppler effect and the Big Bang related? According to the Big Bang theory, the universe is expanding (Landau, 1988, pp. 158−159).

When observing distant galaxies, a redshift is observed—a shift of spectral lines toward the red end of the spectrum. Explaining the redshift using the Doppler effect leads to a conclusion consistent with the theory: galaxies are moving away from each other, and the universe is expanding. Radio navigation devices based on the Doppler effect are widely used to solve a number of basic navigation problems. These radio navigation devices, known as Doppler radio navigation devices, are designed to determine the components of the aircraft's velocity vector relative to a surface reflecting electromagnetic vibrations. They are considered autonomous radio navigation devices, as they do not require additional ground equipment to form a measurement channel.

The aircraft's total velocity vector is the sum of the aircraft's airspeed and wind speed vectors (Andreev, 1960). This vector characterizes the aircraft's speed relative to the earth's surface. In what follows, when describing the Doppler radio navigation system, we will use a rectangular coordinate system in which the Ox-axis coincides with the aircraft's longitudinal axis, the Oz-axis is perpendicular to it, the Oxz-plane is horizontal, and the Oy-axis is perpendicular to the Oxz-plane (Fig. 1). $W = V_r + U_x$

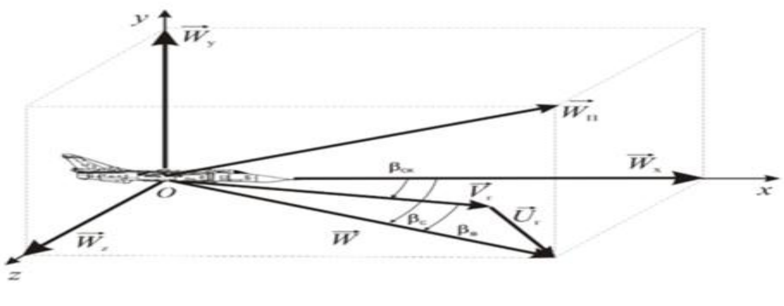

Figure 1. Aircraft Velocity Vector Components

Generally, all three vectors in this coordinate system can have both horizontal and vertical components. Let's denote by the letters W, Vr, and Uг, respectively, the projections of the total speed, airspeed, and wind speed vectors onto the horizontal plane (Golyamina, 1979). These projections, in turn, form a navigational velocity triangle, for which the following relationship holds (Fig. 1). The horizontal component of the aircraft's total speed vector is called the ground speed vector, since it is this component that is taken into account when calculating the aircraft's distance along the Earth's surface. From now on, the vector's magnitude will be referred to as ground speed (Hawking, 2017, p. 232).

Depending on the number of components of the aircraft's total velocity vector that can be measured by a given device, a distinction is made between Doppler total velocity vector meters and Doppler ground speed and drift angle meters. Doppler total velocity vector meters are used for flight control in the vertical and horizontal planes. They are primarily used on helicopters. Some types of these meters also measure the aircraft's true altitude (Effect of Doppler).

Doppler ground speed and drift angle meters measure the aircraft's horizontal velocity vector or the longitudinal components of this vector. They are most commonly used on aircraft, where they serve as the primary sensor in an autonomous dead reckoning navigation system (Wave length and speed). Doppler meters operate in either continuous or pulsed wave modes. Continuous unmodulated or frequency-modulated wave modes are the most common.

Components of the total velocity vector in the horizontal coordinate system; - ground speed vector; - horizontal components of the aircraft airspeed vector and wind speed vector; bc – drift angle; bск – sideslip angle; bв – wind drift angle. In most cases, DISS are used to solve navigation problems in conjunction with an analog or digital navigation computer. In this case, the computer is additionally fed with airspeed data from the airspeed sensor and aircraft heading data from the course system. Such equipment complexes are called autonomous Doppler navigation systems (Golyamina, 1979).

The navigation computer is pre-loaded with the coordinates of the route checkpoints (including the initial and final route points), the values of the specified course angles, and other data. Based on this initial data, the output data of the Doppler meter, and other sensors of the system, the navigation computer solves the following problems: determines the course to the selected route point; Determines the aircraft's current coordinates (geographical or orthodromic); calculates course corrections; the remaining distance and flight time to the selected point, etc. This information is displayed on the corresponding indicators. If necessary, the navigation computer can generate control signals sent to the autopilot to automatically maintain the aircraft on the specified route. In the simplest case, the navigation computer displays ground speed and drift angle values on the corresponding indicators (Andreev, 1960, p. 664). Regarding the change in the oscillation frequency at the receiver, the following explanations are known:

1. When the wave source moves toward the observer, each subsequent wave crest emerges from a position closer to the observer than the crest of the previous wave. Therefore, the distances between crests will be smaller than for a stationary source. This means that the wavelength of the waves arriving at the observer decreases, while their frequency increases (Landau & Lifshitz, 1988).
2. Since the source shifts in the medium over time t = To, by a distance Vu * To, where Vu is the source velocity, the wavelength increases by this amount, and therefore each subsequent wave will need less time to reach the observer.

Consequently, the time between the arrival of successive crests decreases, causing an increase in frequency. Both the first and second explanations involve a change in wavelength, which is unacceptable: classical wave theory allows for changes in wave parameters if the characteristics of the medium in which it propagates have changed (Golyamina & Isakovich, 1979). Furthermore, it was shown above that the Doppler effect does not change wavelength. The author believes that the change in wave frequency at the observer (receiver) can be explained as follows: a moving source imparts additional velocity to the wave (carries it along with its motion), thereby increasing the number of oscillations reaching the observer (receiver) per unit of time. This is similar to how a gramophone record plays out of tune when played at too high a speed, even though the waves recorded on it remain unchanged (Hawking, 2017).

Thus, if the number of incoming waves at the observer (receiver) increases compared to a stationary source, then the source and observer (receiver) are moving closer together. If the number decreases, then they are moving further apart.

The Doppler effect also occurs when waves pass from one medium to another. Let's assume that the wave propagation velocity changes from V1 to V2 during the transition. And at the receiver, N1 and N2 oscillations are received per second, respectively. Then the speed of each oscillation will be:
V1 / N1 and V2 / N2.
Taking the ratios of the velocities, we get:
V2 / V1 = N2 / N1.
Since N2 / N1 are frequency ratios, we can write V2 / V1 = F2 / F1.
This means that a change in wave velocity leads to a change in their frequencies according to the given formula. Thus, the following conclusions can be drawn:

1. With the Doppler effect, the waves do not undergo any changes.
2. The effect is caused by an increase or decrease in the number of waves arriving from the transmitter to the observer (receiver).
3. A change in wave velocity causes an equal change in frequency at the receiver.

Conclusion

The Doppler effect was comprehensively examined during this study. The theoretical part of the work established that the Doppler effect is a universal phenomenon characteristic of all types of waves and particle flows. The discoverer of the effect, Austrian physicist Christian Doppler, first described it while studying sound waves, which was subsequently confirmed in other areas of physics. The practical significance of the study is confirmed by the wide range of applications of the Doppler effect in modern science and technology:

- In radio engineering and communication systems for determining the velocity of moving objects
- In medical diagnostics, particularly in Doppler ultrasound
- In astronomy for studying the motion of stars and galaxies
- In security and speed control systems

The study also focused on the practical application of the effect in medicine. In astronomy, the Doppler effect has become a key tool for studying the motion of celestial bodies and a confirmation of the Big Bang theory. Prospects for further research lie in expanding the application of the Doppler effect in new fields, including quantum technologies and space exploration. Constant technological advances are opening new horizons for the practical use of this fundamental physical phenomenon. Thus, the Doppler effect is not only an important physical phenomenon but also a powerful tool for scientific knowledge, playing a key role in the development of modern science and technology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. About HyperPhysics. (n.d.). http://hyperphysics.phy-astr.gsu.edu/hbase/index.html
2. Arkhangelsky, M. M. (1975). *Physics course: Mechanics*. Prosveshchenie.
3. Andreev, N. N., Vvedensky, B. A., & Vonsovsky, S. V. (1960). *Doppler effect*. In *Physical encyclopedic dictionary* (Vol. 1). State Publishing House "Soviet Encyclopedia".
4. Calc.ru. (n.d.). *Wave length and speed* [Electronic resource]. https://www.calc.ru/Dlina-I-Skorost-Volny.html (Accessed: 31 July 2019).
5. Golyamina, I. P., Isakovich, M. A., & Kitaygorodsky, Yu. I. (1979). *Effect Doppler*. In *Small encyclopedia: Ultrasound.* Soviet Encyclopedia" Publishing House.
6. Gorokhov, A. V. (n.d.). *The relativistic Doppler effect*.
7. Hawking, S. (2017). Short history of time. AST Publishing.
8. Hawking, S. (2017). *A brief history of time*. AST Publishing House.
9. Isakovich, M.A. (1973). *General Acoustics*. Nauka Publishing House.

10. Landau, L. D., & Lifshitz, E. M. (1988). *Field theory* (7th ed., pp. 158–159). *Theoretical Physics, Vol. II)*. Nauka Publishing House.
11. Wikipedia contributors. (n.d.). *Effect of Doppler*. https://ru.wikipedia.org/wiki/Effect_of_Doppler
12. Yavorsky, B. M., & Pinsky, A. A. (1981). *Fundamentals of physics. Volume 2: Oscillations and waves. Quantum physics.* Nauka Publishing House.