Doppler Effect:

This phenomenon, first described by Christian Doppler (Austrian physicist) in 1842. Doppler Effect is the apparent differnce or shift in frequency of a wave that occurs when the wave source, or the detector (Lisner or Observer) of the wave is relatively moving. Doppler effect is applicable to all wave phenomenon as sound waves, electromagnetic waves, microwaves, radio waves, and visible light waves. This phenomeno is used in astronomical mesurements, Mössbauer effect studies, in RADAR, in modern navigation and study of Universe (big bang Theory).

Wavefront of sound source:

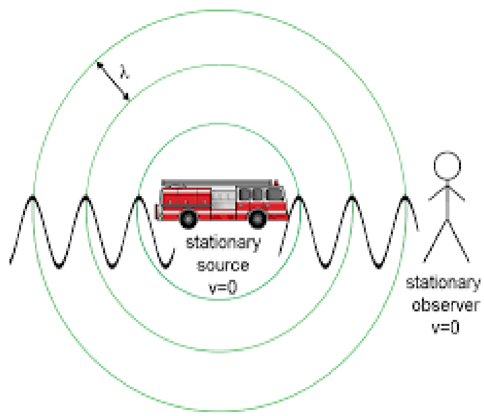


Figure 1: Wavefront of stationary sound source

Figure 1 shows stationary source, Sound waves are created at a constant frequency n_0. The wave front propogates symetrically in all directions away from the source at a constant speed C (speed of sound in the same air madium). The distance beteen the successive wavefronts is the wavelength λ. All observers will hear sound with the same frequency, which will be equal to actual frequency of the wave emitted by the source.

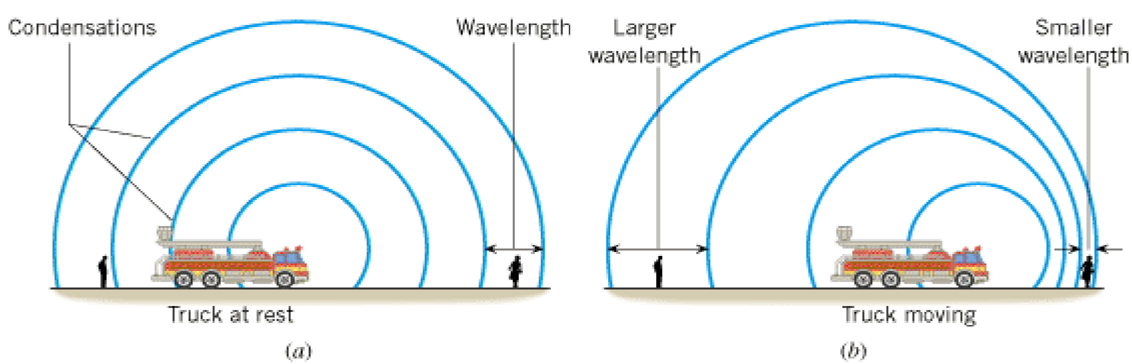


Figure 2: Wavefront of stationary and moving sound source

Figure 2 shows same sound source is producing sound wavs at constant frequncy n_0 in the same medium. Now the source moving to the right with speed Cs and wave length λ. Since the source is moving, the centre of each wavefront is now slightly displaced to the right. As a result, the wavefronts begain to bunch up on the right side (infront of source) and spread apart on the left side(behind the source).

An observer on the right infront of the source will hear a higher frequency $n' > n_0$ and oberver behind the source will hear a lower frequency $n' < n_0$. Infornt of moving object wavefronts are closer with shorter wavelength and higher frquency. Behind object wavefronts are apart with longer wavelength and lower frequency.

Comman experience :

1. As the train approches, the sound of whistle is heard at a high pitch and as the train moved away, the sound of its whistle is heard at a low pitch.

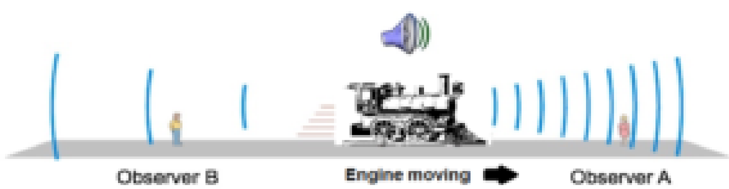


Figure 3: Wavefront for Motion of train

2. Police car or emergency vechile was travelling towards him/her on the highway. As the car approched with its siren , the pitch of the siren sound was high. Then suddenly car passed by, the pitch of the siren sound was low.

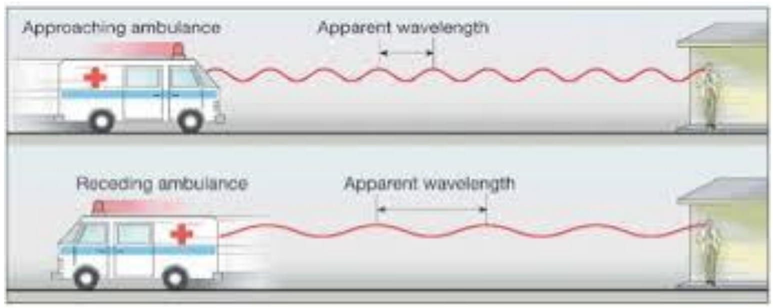


Figure 3: Wavefront for emergency vechile.

In both cases we observe Doppler effect that is a shift in the apparent frequency for a sound wave produced by moving source and not a shift in the actual frequency of the source.

Apparent frequcncies in different cases:

A Source of sound S and Listner L. The sound waves are produced by the source with frequency n and wavelength λ. These sound waves will propagate with velocity C in a madium M. Let source S, lisner L and madium M are in motion with velocities C_S, C_L and C_m along the same direction as shown in figure 5.

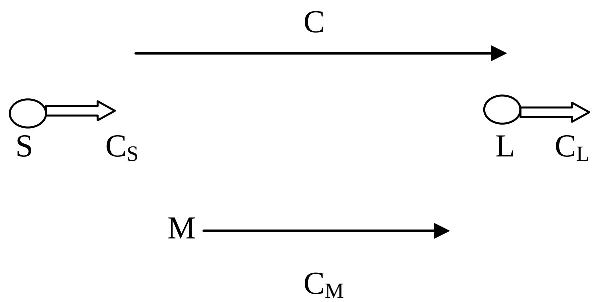


Figure 5: Direction of velocities of Sorce, Lisner and Madium

The relation between frequency, wavelength and velocity of sound wave is C = nλ. The n reprsents number of waves emitted by the source per unit time and time interval is $\frac{1}{n}$. As the medium is moving with speed C_m along the same direction of sound, the effective velocity of sound wave will be $C + C_m$. The distance travel by the first sound wave in time $\frac{1}{n}$ before the emission of second wave will be $\frac{C+C_m}{n}$. The distance travel by source in time $\frac{1}{n}$ will be $\frac{C_s}{n}$. Therefore effective distance travelled by wave in time $\frac{1}{n}$ with respective source will be $\frac{C+C_m}{n} - \frac{C_s}{n}$

Or $\frac{C+C_m - C_s}{n}$. $\lambda' = \frac{C+C_m - C_s}{n}$ Where λ′ will be wavelength of the waves propogating through medium.

The velocity of listner is C_L along the same direction as that of source, medium and sound wave.

The effective velocity of the sound wave with respective listner will be $C + C_m - C_s$.

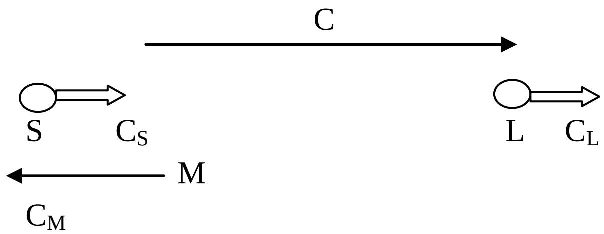
Therefore, frequency of sound waves as heard by liswill be

$$n' = \frac{velocity\ \ of\ \ sound\ \ w.r.t.listner}{distance\ \ travelled\ \ by\ \ sound\ \ in\ time \frac{1}{n} sec} = \frac{C+C_m - C_L}{\lambda'}$$

$$n' = \left(\frac{C+C_m - C_L}{C+C_m - C_s}\right) n$$ where n′ is the apparent frequency of the sound wave heard by listner.

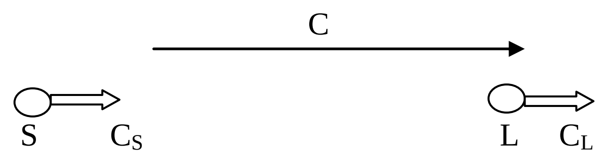
Apparent frequency (pitch of sound) in Doppler effect depends upon relative motion between source and observer. Thus we oberved Doppelr effect in different cases as follows.

Case 1: Let us consider medium is moving in oppsite direction of source then velocity of medium is - C_M. Source and observer are moving in same direction. The apparent frequency is



$n' = \left(\frac{C - C_m - C_L}{C - C_m - C_s}\right) n$ where n′ is the apparent frequency of the sound wave heard by listner.

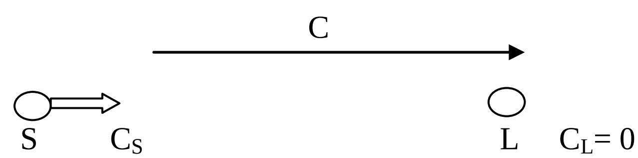
Case 2: Let us consider medium is stationary . Source and observer are moving in same direction



The apparent frequency is

$n' = \left(\frac{C - C_L}{C - C_s}\right)$ n where n′ is the apparent frequency of the sound wave heard by listner.

Case 3: Source is moving towards stationary listner
Let the source velocity C_S and Observer velocty $C_L = 0$.

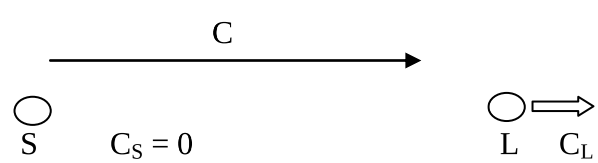


The apparent frequency is n′ > n.

$n' = \left(\frac{C}{C - C_s}\right)$ n where n′ is the apparent frequency of the sound wave heard by listner.

Case 4: Listner is moving away from stationary source.

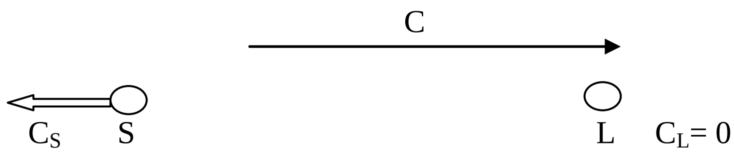
Let the Listner velocity C_L and source velocty $C_S = 0$



The apparent frequency is n′ < n.

n′ $= \left(\frac{C-C_L}{C}\right)$ n where n′ is the apparent frequency of the sound wave heard by listner.

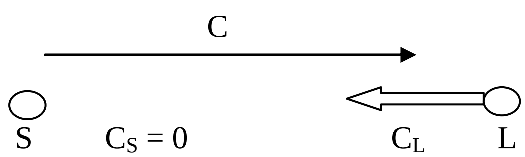
Case 5: Source is moving away from stationary listner.



The apparent frequency is n′ < n.

n′ $= \left(\frac{C}{C+C_s}\right)$ n where n′ is the apparent frequency of the sound wave heard by listner.

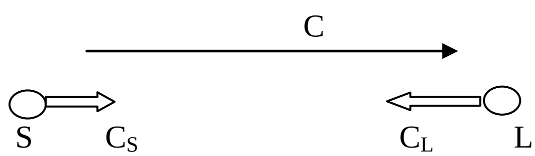
Case 6: Listner is moving towards stationary source.



The apparent frequency is n′ > n.

n′ $= \left(\frac{C+C_L}{C}\right)$ n where n′ is the apparent frequency of the sound wave heard by listner.

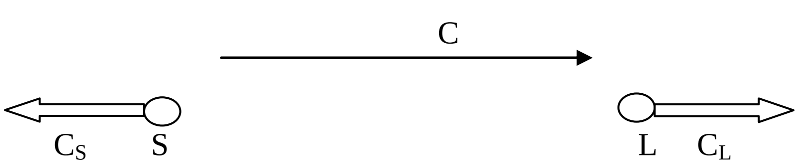
Case 7: Source and listner are moving towards each other.



The apparent frequency is n′ > n.

n′ $= \left(\frac{C+C_L}{C-C_s}\right)$ n where n′ is the apparent frequency of the sound wave heard by listner.

Case 8: Source and listner are moving away each other.

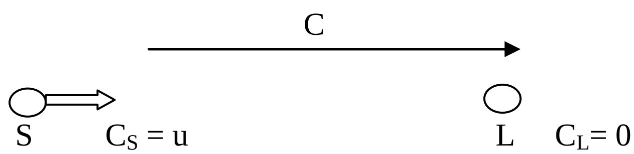


The apparent frequency is n′ < n.
where n′ is the apparent frequency of the sound wave heard by listner.

Asymetric nature of Doppler effect in sound

For asymetric natrure of Doppler effect in sound we consider two cases with same velocity of source in both cases. When the source and listner moving in same direction, the apparent frequency of the sound waves heard by listner is $n' = \left(\frac{C-C_L}{C+C_s}\right)$ n.

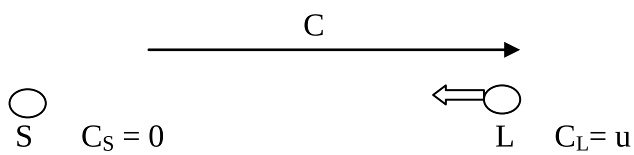
Case 1: Source is moving towards stationary listner with velocity u.
Let the source velocity C_S = u and listner velocty C_L= 0.



The apparent frequency is

$n' = \left(\frac{C}{C-u}\right)$ n where n′ is the apparent frequency of the sound wave heard by listner.

Case 2: Listner is moving towards stationary source with velocity u.
Let the source velocity C_S = 0 and listner velocty C_L= u.



The apparent frequency is

$n'' = \left(\frac{C+u}{C}\right)$ n where n′ is the apparent frequency of the sound wave heard by listner.

Thus in both the cases the relative velocity between source and listener is u.

The difference between two frequencies

$n' - n'' = \left(\frac{C}{C-u}\right) n - \left(\frac{C+u}{C}\right) n = \left(\frac{u^2}{C(c-u)}\right)$ n. however $u^2 > 0$ and c > u.

$n' - n'' \neq 0$ then $n' \neq n''$.

Thus $n' \neq n''$ the Doppler effect in sound is asymetric in nature.