Doppler's Effect and Musical Sound

Doppler's Effect and Musical Sound

- The change in frequency or wavelength observed by observer due to relative motion between source and observer.
- Doppler's effect is independent of distance between source and observer.
- Doppler's effect observed in both light wave and sound wave.

Limitations of Doppler's effect in sound

- The velocity of observer (v_0) must be less than the velocity of sound (v) i.e. $\mathrm{v}_0 < \mathrm{v}$.
- The velocity of source of sound (v_s) must be less than the velocity of sound i.e. $\mathrm{v}_s < \mathrm{v}$.
  $\Rightarrow$ If the velocity of source of sound is greater than that of sound than due to shock waves the wave front get distorted, consequently the change in frequency will not be observed by the observer.

Application of Doppler's effect

- in RADAR
- in SONAR
- in ECG
- to determine velocity of star and galaxies
- to determine the width of spectral lines
- in tracking if artificial satellites.

Doppler's effect in sound

v = velocity of sound

v_0 = velocity of observer

v_s = velocity of source

f = Actual frequency

$\mathrm{f'}$ = Apparent frequency

i. When source is stationary and observer is in motion.

a. If observer is moving towards source than apparent frequency is given by

$$f' = \left(\frac{v + v_0}{v}\right) f$$

In this case $\mathrm{f'} > \mathrm{f}$

% increase in frequency = $\frac{100 v_o}{v}$

b. If observer is moving away from the source then apparent frequency is given by

$$f' = \left(\frac{v - v_0}{v}\right) f$$

In this case $\mathrm{f'} < \mathrm{f}$

% decrease in frequency = $\frac{100 v_o}{v}$

ii. When source is in motion and observer is at rest:

a. If source is moving towards observer then apparent frequency is given by

$$f' = \left(\frac{v}{v - v_s}\right) f$$

In this case: $\mathrm{f'} > \mathrm{f}$

b. If source is moving away from observer then apparent frequency is given by

$$f' = \left(\frac{v}{v + v_s}\right) f$$

In this case: $\mathrm{f'} < \mathrm{f}$

iii. When both source and observer are in motion:

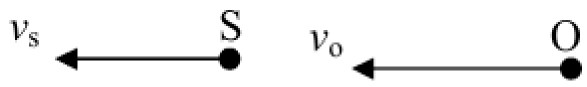
a. If both are approaching each other then,

$$f' = \left(\frac{v+v_0}{v-v_s}\right) f$$

b. If both are moving away from each other,

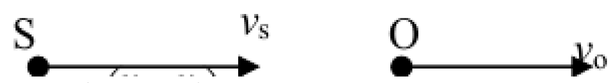
$$f' = \left(\frac{v-v_0}{v+v_s}\right) f$$

c. If observer is moving towards source and source is moving away from observer then,



$$f' = \left(\frac{v+v_0}{v+v_s}\right) f$$

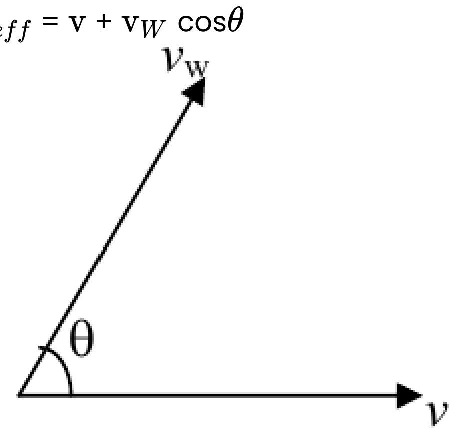
d. If source is moving towards observer and observer is moving away from source then,



$$f' = \left(\frac{v-v_0}{v-v_s}\right) f$$

⇒ If the wind blows with velocity V_W having direction making an angle θ with the direction of propagation of sound towards the observer, then velocity of sound (V) is replaced by v_{eff}.

v_{eff} = v + v_W cosθ



i. If wind blows in the direction of sound, then, θ = 0,
v_{eff} = v + v_W

ii. If wind blows opposite to the direction of sound, then, θ = 180○
v_{eff} = v -v_W

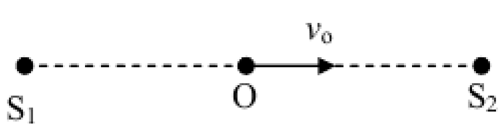
⇒ The apparent frequency of whistle of an engine changes in the ratio $\mathrm{f}_1/\mathrm{f}_2$ as engine passes a stationary listener. Then the velocity of engine (source)

$$V_s = \left(\frac{\frac{f_1}{f_2}-1}{\frac{f_1}{f_2}+1}\right) v$$

⇒ The frequency of sound of a car horn as perceived by listener towards whom the car is moving differs from the frequency of horn by x% then the velocity of car (source) is

$$v_s = \frac{v \times x}{100+x}$$

iv. When observer moves between two distant sources:



Frequency of both source = f

and observer is moving towards source S_2.

i. For source S_2 observer is approaching and apparent frequency is given by

$$f' = \left(\frac{v+v_0}{v}\right) f$$

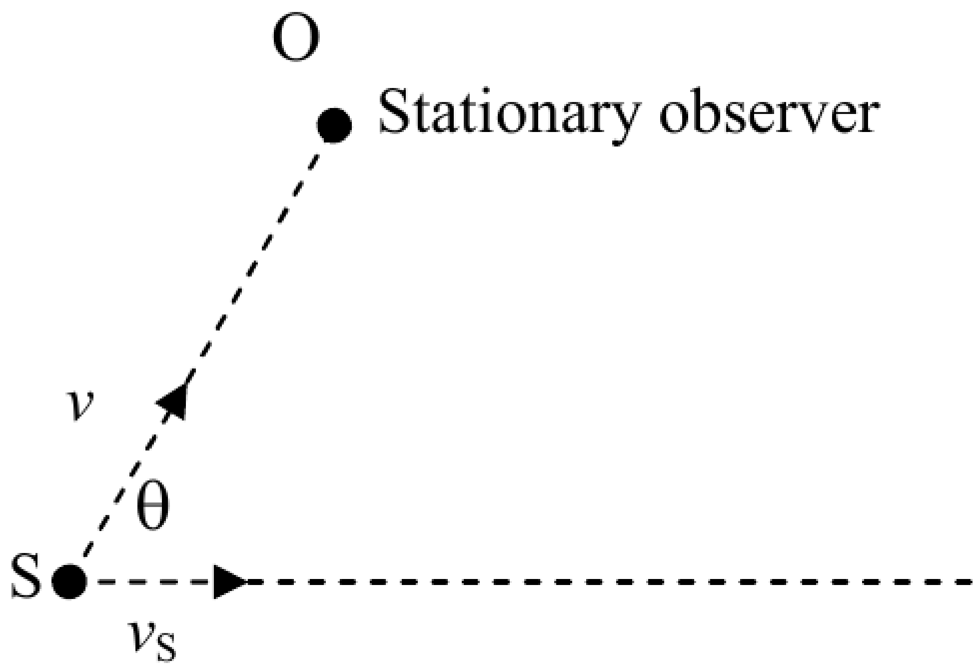
ii. For source S_1 observer is moving away and apparent frequency is given by

$$f' = \left(\frac{v-v_0}{v}\right) f$$

Beats heard by observer Δf = f' -f''

$$\Delta f = \frac{2v_0}{y} f$$

v. Doppler's effect when the source is moving in a direction making an angle θ with respect to observer:



Apparent frequency is given by

$$f' = \left(\frac{v}{v - v\cos\theta}\right) f$$

$\Rightarrow$ When an astronaut in a rocket/space vehicle moving towards reflector receives its own signal from reflector, then change in frequency occurs in two steps.

i. Due to motion of source:
$$f_1 = \sqrt{\frac{C+v}{C-v}} f$$
ii. Due to motion of approaching observer: $f_2 = \sqrt{\frac{C+v}{C-v}} f_1$

Change in frequency:
$$\Delta f = \frac{2v}{C} \times f \text{ and } \Delta\lambda = \frac{2v}{C} \times \lambda$$
where,
v = velocity of rocket/space vehicle
C = velocity of light = 3 $\times$ 10^8 m/sec

Doppler's effect in light

Change in frequency,

$$\Delta f = \frac{v}{C} \times f$$

and change in wavelength is given by:

$$\Delta\lambda = \frac{v}{C} \times \lambda$$

Musical sound

Characteristics of musical sound:

i. loudness
ii. pitch
iii. quality and timber

Loudness

It is the degree of sensation produced in ear it depends on the intensity as well as sensitiveness of ear. Its unit is Phon.

L = K log I

- The level of sound is measured in **bel** or **decibel**.
  no. of bel; n = $\log_{10}(I/I_0)$
  no. of decibel; n = 10 $\log_{10}(I/I_0)$

where,
I_0 = reference intensity level = 10^{-12} W/m^2

- If n_1 and n_2 are the no. of decibels of intensity of sound I_1 and I_2 respectively then,
  $n_2 - n_1$ = 10 log (I_2/I_1)
  $I \propto A^2 \propto \frac{1}{d^2}$
  $\therefore n_2 - n_1 = 20 log \frac{A_2}{A_1} = 20 log \frac{A_2}{A_1}$
  where
  A = Amplitude
  and d = distance from point source

Pitch

- It depends on frequency.
- Distinguish shrill note and grave note.
- High pitch voice shriller
  e.g.: voice of female, child, mosquito etc.
- Low pitch, voice grave
  e.g. male, lion etc.

Quality or Timber

i. It depends on the presence of overtones.
ii. Due to quality of sound one can recognized the voice of other without seeing.

- Sweetness of sound depends upon its periodicity and regularity.
- Threshold of frequency: db (decibel) $\rightarrow$ 0; I = 10^{-12}
- Threshold of pain: db $\rightarrow$ 120; I = 1
  i. Unison means same frequency.
  ii. Fifth means frequency 1.5 times.
  iii. Octave means frequency double.