1. INTRODUCTION

The apparent change in frequency or wavelength observed by the observer when there is a relative motion between the source and the observer, is known as Doppler Effect.

Doppler's effect takes place both in sound and light. In sound it depends on whether the source or observer or both are in motion, while in light it depends only on the fact that whether the distance between source and observer is decreasing or increasing.

2. CONDITIONS WHEN DOPPLER EFFECT IS OBSERVED FOR SOUND WAVES

(a) When the source of sound is in motion and the observer at rest.

(b) When the observer is in motion and the source at rest

(c) When the source and the observer are moving with unequal velocities.

(d) When the source and the observer and intervening medium are in motion.

3. LIMITATIONS OF DOPPLER EFFECT IN SOUND

(a) The velocity of source of sound must be less than that of sound i.e. $v_s < v$

(b) The velocity of observer must be less than the velocity of sound i.e. $v_0 < v$

(c) If the velocity of sound source is greater than that of sound then due to shock waves the wavefront gets distorted, consequently the change in frequency will not be observed by the observer.

4. CONDITIONS WHEN DOPPLER EFFECT IS NOT OBSERVED FOR SOUND WAVES

(a) When the source of sound and the observer both are at rest then Doppler effect in sound is not observed.

(b) When the source and the observer both are moving with same velocity in same direction.

(c) When the source and the observer are moving mutually in perpendicular directions.

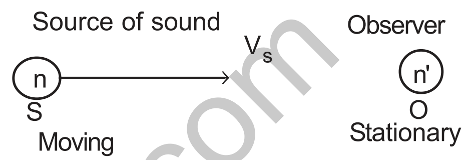
(d) When the medium only is moving

(e) When the distance between the source and the observer is constant.

5. APPARENT FREQUENCY OF SOUND HEARD BY THE OBSERVER WHEN SOURCE IS IN MOTION AND OBSERVER IS AT REST.

(1) When source is in motion and observer is at rest then the cause of apparent change in frequency is that the waves either contract or expand.

(i) When source moves towards the observer: wavelength decreases. Apparent frequency is given by

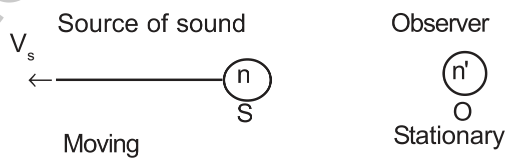


$$n' = n\,\frac{v}{(v - v_s)}$$

$\because\ v - v_s < v \quad \therefore\ n' > n$

(ii) When source moves away from the observer : wavelength increases.

Apparent frequency is given by



$$n' = n\,\frac{v}{v + v_s}$$

$\because\ (v + v_s) > v \quad \therefore\ n' < n$

Apparent wavelength $\lambda' = \lambda\,\frac{(v + v_s)}{v}$

$\because\ (v + v_s) > v \quad \therefore\ \lambda' > \lambda$

Ex.1 A jet plane emits sound with a frequency 990 cycles/sec and carries on board a source of light emitting radiation of wavelength 4500 Å. If the jet plane approaches the airport with a velocity 1080 km/hr, find,

(i) the frequency of sound heard by the observer on airport. (Velocity of sound v = 330m/s, velocity of light c = 3×10^8m/s)

(A) 10890 cycles/sec

(B) 18090 cycles/sec

(C) 10980 cycles/sec

(D) 10089 cycles/sec.

Sol. The source is approaching the observer, therefore the observed frequency,

$$n' = \frac{v}{v - v_s} n$$

Given v = 330m/s, v_s = 1080 km/hr = 300m/s, n = 900 sec^{-1}

$$\therefore \; n' = \frac{330}{330 - 300} \times 990 = 10890 \; \frac{\text{cycles}}{\text{sec}}$$

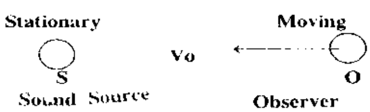
Apparent wavelength is given by

$$\lambda' = \lambda \frac{(v - v_s)}{v}$$

$\because \; v - v_s < v \qquad \therefore \; \lambda' < \lambda$

6. APPARENT FREQUENCY OF SOUND HEARD BY THE OBSERVER WHEN THE SOURCE IS AT REST AND THE OBSERVER IS IN MOTION.

(i) When the observer approaches the source: then frequency increases.



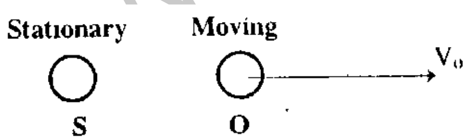
$$n' = n \frac{[v + v_0]}{v}$$

$\because \; v + v_0 > v \qquad \therefore \; n' > n$

$$\lambda' = \lambda \frac{v}{[v + v_0]}$$

$\because \; v + v_0 > v \qquad \therefore \; \lambda' < \lambda$

(ii) When the observer moves away from the source: then frequency decreases.



$$n' = n \frac{[v - v_0]}{v}$$

$\because \; v - v_0 < v \qquad \therefore \; n' < n$

$$\lambda' = \lambda \frac{v}{[v - v_0]}$$

$\because \; v - v_0 < v \qquad \therefore \; \lambda' > \lambda$

Ex.2 With what velocity should an observer approach a stationary sound source so that the apparent frequency of sound should appear double the initial frequency ?

(A) $v_0 = \frac{v}{2}$ (B) $v_0 = 3v$

(C) $v_0 = 2v$ (D) $v_0 = v$

Sol. $n' = 2n, \; v_0 = ?$ .... (1)

$$n' = n \frac{[v + v_0]}{v} \qquad \text{......... (2)}$$

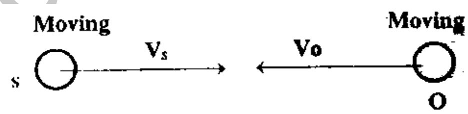
From equation (1) & (2)

$$2n = n \frac{[v + v_0]}{v}$$

$2v = v + v_0 \qquad \therefore \; v_0 = v$

7. APPARENT FREQUENCY HEARD BY THE OBSERVER WHEN BOTH SOURCE & OBSERVER ARE MOVING.

(i) When both moves towards each other



$$n' = n \left[\frac{v + v_0}{v - v_s}\right] \; \& \; \lambda' = \lambda \left[\frac{v - v_s}{v + v_0}\right]$$

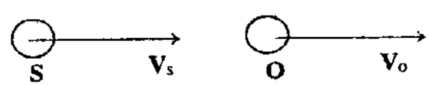
$n' > n \qquad \& \qquad \lambda' < \lambda$

(ii) When both moves away from each other

$$n' = n \left[\frac{v - v_0}{v + v_s}\right] \; \& \; \lambda' = \lambda \left[\frac{v + v_s}{v - v_0}\right]$$

$n' < n \qquad \& \qquad \lambda' > \lambda$

(iii) When the source is approaching the receding observer



$$n' = n \left[\frac{v - v_0}{v - v_s}\right] \; \& \; \lambda' = \lambda \left[\frac{v - v_s}{v - v_0}\right]$$

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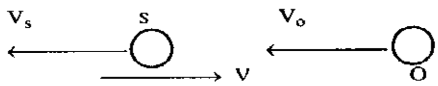
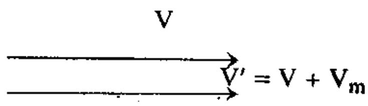
(iv) When the observer is approaching the receding source.



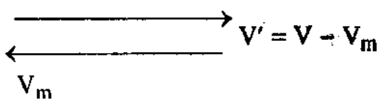
$$n' = n\left[\frac{v+v_0}{v+v_s}\right] \;\&\; \lambda' = \lambda\left[\frac{v+v_s}{v+v_0}\right]$$

Note :-

(A) If the medium is moving with velocity v_m in the direction of sound then the velocity of sound becomes $(v + v_m)$



(B) If the medium is moving with velocity v_m in a direction opposite to that of sound, then the velocity of sound becomes $(v - v_m)$.



(C) In all the above formulae v will have to be replaced by $(v \pm v_m)$ according to situation given.

Ex.3 If a sound source of frequency n approaches an observer with velocity v/4 and the observer approaches the source with velocity v/5 then the apparent frequency heard will be -

(A) $\frac{5}{8}n$ (B) $\frac{8}{5}n$ (C) $\frac{7}{5}n$ (D) $\frac{5}{7}n$

Sol. $v_s = \frac{v}{4}$, $v_0 = \frac{v}{5}$

$$n' = n\frac{[v+v_0]}{[v-v_s]} \quad \{s \rightarrow \leftarrow 0\}$$

$$n' = n\left[\frac{v+\frac{v}{5}}{v-\frac{v}{4}}\right] \qquad n' = n\left[\frac{6}{5}\times\frac{4}{3}\right] = \frac{8}{5}n$$

Ex.4 A source and a detector move away from each other, each with a speed of 10m/s with respect to the ground with no wind. If the detector detects a frequency 1950Hz of the sound coming from the source, what is the original frequency of the source? Speed of sound in air = 340m/s

(A) 2700Hz (B) 2007Hz
(C) 2070Hz (D) 2170Hz

Sol. If the original frequency of the source is ν, the apparent frequency heard by the observer is

$$\nu' = \frac{v-v_0}{v+v_s}\nu$$

$$1950 = \frac{350-10}{340+10}\nu$$

$$\Rightarrow \quad \nu = \frac{35}{33} \times 1950 = 2070 \text{ Hz}$$

8. APPARENT CHANGE FREQUENCY HEARD BY THE OBSERVER

(i) When observer crosses the stationary source.

$$n' = n\left[\frac{v+v_0}{v}\right] \quad n'' = n\left[\frac{v+v_0}{v}\right]$$

$$\Delta n = n' - n'' = \frac{2nv_0}{v}$$

(ii) When moving source crosses a stationary observer.

$$n' = \frac{nv}{(v-v_0)} \;, \quad n'' = \frac{nv}{(v+v_s)}$$

$$\Delta n = n' - n'' = \frac{2nv_0}{\left[1-\frac{v_s^2}{v^2}\right]}$$

$$\Delta n = \frac{2nv_s}{v} \quad \left[\because \left(\frac{v_s}{v}\right) << 1\right]$$

9. DOPPLER'S EFFECT IN LIGHT

The velocity of light in free space is independent of the motion of source or observer and it is a universal constant given as $c = 3 \times 10^8$m/s. Thus the doppler's effect in light depends only upon the relative motion of the light source and the observer and it does not matter which one is moving.

(i) When a light source and an observer are approaching each other with a velocity v, then the apparent frequency of light will be .

$$\nu' = \nu$$

and $\nu' = \nu\,(1 - v/c)$ if $v << c$

or $\Delta\nu = -\,\nu\, v/c$

Case (a) When the light source is going away from the earth then

$\Delta\nu = \nu$

$\nu' < \nu$ and $\Delta\lambda = \lambda$ or $\lambda' > \lambda$ i.e. λ is increased or spectral line will shift towards the red end of the spectrum. This is known as red shift.

Case (b) When the light source is coming nearer to earth.

$\Delta\nu = \nu$ or $\nu' > \nu$

and $\Delta\lambda = -\lambda$ or $\lambda' < \lambda$

$\Rightarrow$ wavelength appears to be decreasing i.e. the spectral line in electromagnetic spectrum gets displaced towards violet end, hence it is known as violet shift.

10. DIFFERENCE BETWEEN DOPPLER EFFECT IN SOUND AND LIGHT

S.No.	Doppler effect in sound	Doppler effect in light
1	This effect depends upon whether the source the is in motion or the observer is in motion	This effect depends upon the relative motion between source and the observer and not on the motion of the observer or the source.
2.	The velocity of medium affects the apparent frequency.	The velocity of medium does not contribute to this effect frequency
3.	Ordinary law of addition of velocities is applicable in this	Law of addition of velocities of relativistic mechanics is applicable in this.
4.	Transverse Doppler effect is not applicable in this	Transverse Doppler effect is applicable in this.

11. APPLICATION OF DOPPLER EFFECT

(1) To determine the width of spectral lines (ΔW).

(2) To determine the velocity of stars and galaxies.

(3) To determine the frequency of a tuning fork.

(4) To determine the speed of rotation of sun.

(5) In the discovery of Saturn rings.

(6) In the discovery of twin stars.

(7) In E.C.G.

(8) In very high frequency unidirectional radio ranging (V.O.R.)

(9) In tracking of artificial satellites.

(10) In RADAR

(11) In SONAR.

12. POINTS TO REMEMBER

(1) Doppler effect is valid for all types of waves because this is a universal property of waves.

(2) Doppler effect in light is explained on the basis of Einstein's theory of relativity.

(3) Transverse Doppler effect.When the source is moving at right angle to the observer or the observer is moving at right angles to the source, then the apparent change in the frequency of light source is known as transverse Doppler effect.

(4) The wavelength observed in front of a source is less and that observed behind the source is more.

(5) Pitch is that feeling which produces a sensation of sound being sharp or thick.

(6) Doppler effect of sound not only depends on the relative motion between the sound source and the observer, but also depends upon whether the source is moving or the observer is moving.

(7) Direction of sound is always taken from the source towards the observer.

(8) Doppler effect in sound is used in estimating the velocity of an aeroplane in air.

(9) Doppler effect in light can be used to estimate the speed of stars and galaxies.

(10) The velocity of a submarine moving under water can also be detected by observing the changes in frequency of the sound waves sent to the submarine and reflected by it.

(11) If velocity of source of sound is greater than that of sound. (i.e. $v_s > v$), then the source will overtake the sound waves and under this condition Doppler's effect will not be observed.

(12) If velocity of observer is greater than the velocity of sound i.e. $v_0 > v$, it means observer is receding away from the source the wave will never reach the observer and consequently Doppler effect will not be observed.

(13) The width of a spectral line can also be explained from the Doppler's effect. This width is given by $2\Delta\lambda = 2(v/c)\lambda$.

(14) When the source (s) and the observer (O) are approaching each other then $n' > n$. & $\lambda' < \lambda$

(15) When S and O are receding away from each other then $n' < n$ & $\lambda' > \lambda$.

(16) When S and O are moving in the same direction with same speed then $n' = n$ & $\lambda' = \lambda$.

(17) $\Delta\lambda$ depends upon

(a) velocity of source

(b) velocity of observer

(c) frequency

(d) wavelength.