S. Y. B. Sc. Physics I (SEM-IICBCS) Oscillations, Waves & Sound

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Chapter 5

Sound and Doppler Effect

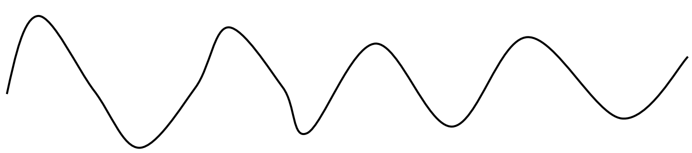
Introduction-

Sound is a vibration that propagates as acoustic waves, through a transmission medium such as a gas, liquid or solid. Sound is a wave that is created by vibrating objects and propagated in medium.

Depending upon the frequency range, waves can be classified into three categories

1. **Audible** waves or sound waves- The waves having frequency range between 20 Hz to 20 KHz and can be heard by human ears. These waves are produced by vibrating bodies such as vocal cords, air column and musical instruments.
2. **Infrasonic** waves- The waves having frequency below audible limit i.e. 20 Hz. These waves are produced by large vibrating bodies e.g. vibrations during earthquakes, vibrations of pendulum. Human ear is not sensitive to these waves.
3. **Ultrasonic** waves- The waves having frequency higher than 20 KHz i.e. above the limit of human audibility. Human ear is not sensitive to these waves. Animals like dogs, birds and bats are sensitive to these waves.

Audible sounds are classified into two groups, **musical sound** and **noise**



Musical sound –It is pleasant, continuous and uniform sound produced by regular and periodic vibrations. E. g. tuning fork, piano etc, musical sound produce pleasing sensation on human ear.

Noise – It is unpleasant, discontinues and non –uniform sound produced by irregular succession of disturbance, All sounds other than musical notes are noise. e. g. sound produced by crackers, factory and moving vehicles etc, sudden changes in loudness.

1. **Intensity of sound-**The sound energy crossing per unit area around a point in one second is called intensity of sound. The sound intensity is proportional to the square of the wave amplitude.

$$I = 2\pi^2 \rho\, c\, n^2 a^2$$

n = frequency

ρ = density of medium

a = amplitude, and c = velocity of wave.

SI unit of intensity is watt per square meter (Watt/m^2)

$$I \propto P^2$$

Where, P is pressure amplitude, I = 10^{-12}W/m^2

Intensity depends upon,

1. Amplitude- $I \propto a^2$
2. Surface area- $I \propto A$
3. Distance between source and listener- $I \propto \frac{1}{d^2}$
4. Density of the medium- Greater is the density of medium, more is the intensity of sound
5. Motion of air- If air is blowing in the direction of propagation of sound waves, intensity of sound increases and vice versa.

2. **Loudness of sound-** musical sound by which a loud sound can be distinguish from faint sound even if two have the same pitch, called loudness or intensity of sound near the ear is high, loudness will be more.

   Loudness depends upon,

   1. Amplitude of vibration- Greater the amplitude of vibration, greater is loudness.
   2. Motion of the medium- loudness increased in the direction of propagation of waves
   3. Surface area of vibrating body- Loudness is directly proportional to surface area of the source of sound.
   4. Frequency of the source- The loudness of vibrating body is directly to square of frequency of body.

Intensity level in decibel = $(dB) = 10 log_{10} \frac{I}{I_0}$

Unit of intensity is Watt/m^2, Intensity of least audible sound is, (I_0= 10^{-12}Watt/m^2)

$$dB\ = 10log_{10}\frac{I}{I_0} = 10log_{10}\frac{10^{-12}}{10^{-12}} = 0\ dB$$

If sound has intensity 1W/m^2, then intensity level is.

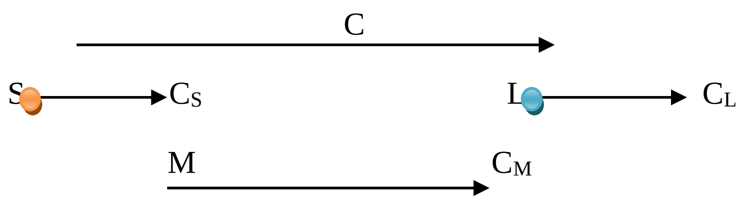
$$dB\ = 10log_{10}\frac{I}{I_0} = 10log_{10}\frac{1}{10^{-12}} = 10log_{10}10^{12} = 120dB\ \ or 12bel$$

(1 bel = 10 decibel)

Doppler effect-

Expression for Apparent frequencies of different cases-

Consider a source of sound S and listener L. Sound waves are produced by source with frequency n and wavelength λ. These sound waves will propagate with velocity c in medium M.



Let the source S, listener L and medium M are in motion with velocities C_S, C_L and C_M along the same direction respectively.

$$n' = \frac{\text{velocity of sound w.r.t listener}}{\text{distance travelled by sound in time t}}$$

$$n' = \frac{c + c_m - c_L}{\lambda'}$$

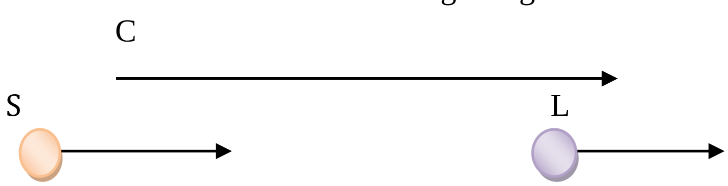
$\lambda' = \frac{c+c_m-c_s}{n}$ Put in above equation,

$n' = (\frac{c+c_m-c_L}{c+c_m-c_s})$ n

n' Is apparent frequency

Difference cases-

1. Source and listener are moving along same direction-



$n' = (\frac{c-c_L}{c-c_S})$ n

1. Asymmetric Nature of Doppler effect-(Sound Waves)

When source of sound and listener are moving along the same direction, the apparent frequency of the sound as heared by the listner is given by,

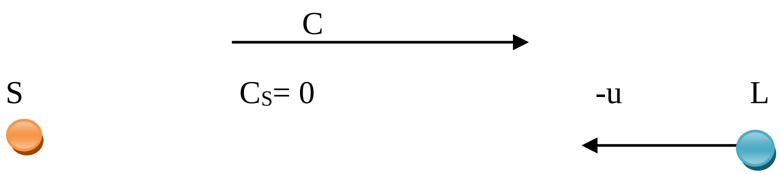
$n' = (\frac{c - c_L}{C - C_S})$ n

Let us consider two cases,

1. Source is moving towards stationary listener with velocity u:

$n' = (\frac{C}{C - u})$ n

2. Listener is moving towards the stationary source with velocity u:



$$n'' = \left(\frac{c + u}{c}\right) n$$

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

$n'' - n' = (\frac{C}{C - u})$ n--$\left(\frac{c+u}{c}\right)$ n

$= \frac{u^2}{c\ (c - u)}\ n$

Now, $u^2 > 0\ and\ c > u$

$$n' - n'' \neq 0$$

$$n' \neq n''$$

In same relative motion condition, inequality of two apparent frequency, so Doppler effect in sound is asymmetric in nature.

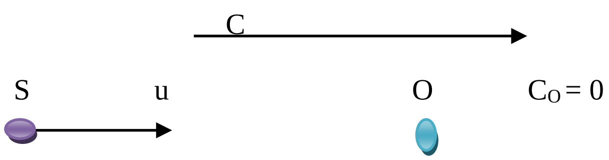
2. Symmetric nature of Doppler effect in light-

When light, source of light and observer are moving along the same direction, the apparent frequency of light observed by the observer is given as,

$n' = \frac{c - c_O}{c - c_S}$

To show the symmetric nature of Doppler effect in light, let us consider two cases,

1. **Source of light is moving towards stationary observer with velocity u:**



using $C_{O=0}$ and $C_S = u$ in above equation,

$n' = (\frac{C}{C-u})$ n

i.e. $n' >$ n

Thus, when source is moving towards the stionary observer, there is incresse in apparent frequency.

Multiply and divide c in above equation,

$$n' = \frac{1}{1 - \frac{u}{c}} \text{ n}$$

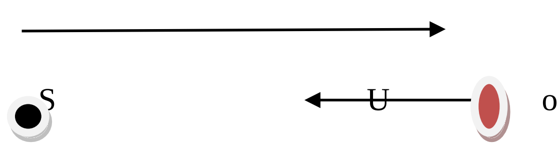
$$n' = (1 - \frac{u}{c})^{-1} \text{n}$$

Here, $C_S \ll$ C

So,

$$n' = (1 + \frac{u}{c})^{1} \text{n}$$

2. **The observer is moving towards the stationary source with velocity u:**



$n'' = (1 + \frac{u}{c})^{1}$n

Doppler Effect in Light-

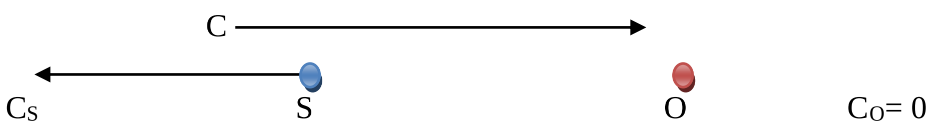
If light energy is propagates in the form of wave, the apparent frequency of light observed by the observer is given by,

$$n' = \frac{C - C_O}{C - C_S}$$

In case of light the velocity of light is very large as compaired to the velocity of observer.i.e c = nλ

Let us consider two cases,

Case1. Source of light moving away from the stationary observer-e.g. star is moving away from stationary observer on the earth.

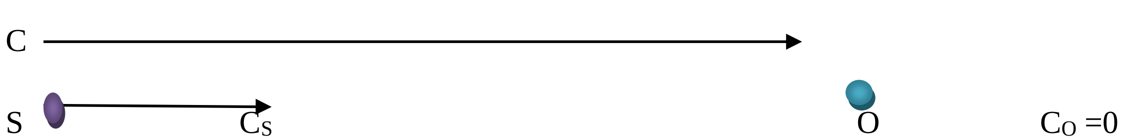


$$d\lambda = \frac{C_S}{C}\lambda$$

Since, C_S, C and λ are positive, $d\lambda > 0$

Thus, change in wavelength is positive i.e. apparent wavelength of light increase when source is moving away from the stationary observer on earth. So spectral lines of star are shifted towards the red end is called red shift.

Case2. Source of light moving towards the stationary observer-e.g. star is moving towards stationary observer on the earth.



$$d\lambda = -\frac{C_S}{C}\lambda$$

Since, C_S, C and λ are positive, $d\lambda < 0$

Thus, change in wavelength is negative i.e. apparent wavelength of light decreases when source is moves towards the stationary observer on earth. So spectral lines of star are shifted towards the violet end is called violet shift or blue shift.

Applications of Doppler Effect-

1. **RADAR-** the Radio detection and Ranging System is called RADAR. Radio waves are electromagnetic waves. Radio waves are given out from system get reflected from moving object like airplane, automobile, these reflected waves are recorded by the system having different frequency with the frequency of emitted waves. These two waves produce beats. According to Doppler Effect.
2. **Width of spectral line-** In spectrum, the excited atoms of gas give out radiations like light rays. Having random motion, hence the apparent frequencies of photons from different atoms which are entering the slit of the spectrometer are different. So spectral lines have different width. The half width of the spectral line is

   $w = \upsilon\sqrt{\frac{T}{A}}$ Where υ is frequency, T is temperature and A is atomic weight of the gas.
3. **Red shift** - If star is moving away from the earth and if we take spectrum of light from moving star, the spectral line corresponding to the star will shift towards the red end of stationary spectrum is called red shift. Thus when red shift is observed, the star is moving away from the observer situated on earth.
4. **Violet shift-** If star is moving towards the earth, the spectral line of the spectrum of star which is shifted towards the violet end of the spectrum called violet shift. i. e. star is moving towards the earth.

   If we are able to detect the red or violet shift, we can measure the speed of the star.