Quick Notes

Sunday, April 25, 2021 9:57 PM

Content Review: [10mins]

Sound Level β

- The **sound level** β of any sound is given by

$$\beta = 10 \log \frac{I}{I_0} \qquad \text{measured in decibels (dB)}$$

where I is the **intensity of the sound** and I_0 is the **reference intensity** (typically the human threshold of hearing $I_0 = 1 \times 10^{-12}\ \mathrm{W/m^2}$

- The **intensity** I is inversely proportional to the distance squared

$$I \propto \frac{1}{r^2}$$

- If there is more than one source of sound, then the total intensity is stacked linearly. In other words, if one source of sound has intensity I, then n identical sources would have total intensity $I_{\text{net}} = n\,I$

Doppler Effect

- The **Doppler Effect** is the result of the spatial distortion of sound waves due to a moving source and/or a moving observer.
  - This effect is the stretching/compressing of the spacing between wave peaks, resulting in a lower/higher perceived frequency.
- **Rule of Thumb:**

decreasing distance b/w source & observer $\longrightarrow$ higher observed frequency

and vice versa: increasing distance $\longrightarrow$ lower observed frequency

- The **observed frequency** f_{obs} is given by

$$f_{\text{obs}} = \left[\frac{v \pm v_{\text{obs}}}{v \mp v_{\text{src}}}\right] f_{\text{src}} \qquad \text{where } f_{\text{src}} \text{ is the source frequency}$$

The **sign** ($\pm$) of the velocities v_{obs} and v_{src} can be determined *qualitatively* based on our **Rule of Thumb** mentioned above, looking at the relative motion of the source and observer.

Two Firecrackers

If two firecrackers simultaneously produced a sound level of 95 dB when fired simultaneously at a certain place, what would the sound level be if only one exploded?

FIND β_1 ~ 1 FIREWORK

$\beta_2 = 10 \log \frac{I_2}{I_0}$ WHERE I_2 ~ INTENSITY OF 2 FIREWORKS

β_2 ~ SOUND LEVEL OF 2 FIREWORKS

$\beta_2 = 95\ dB$

WE WANT TO FIND $\beta_1 = 10 \log \frac{I_1}{I_0}$ ~ SOUND LEVEL OF 1 FIREWORK

If one source of sound has an intensity measured to be *I* at some point. Then two sources of sound will have intensity *2*I*; and three sources of sound will have intensity *3*I*

In general, the net intensity of *n* sources is given by *I_net = n * I*

$I_1 = \frac{I_2}{2}$ OR $I_2 = 2 I_1$

$\beta_1 = 10 \log \frac{I_1}{I_0} = 10 \log \left[\frac{I_2/2}{I_0}\right] = 10 \log \left[\frac{I_2/I_0}{2}\right]$

RECALL: $\log\left[\frac{a}{b}\right] = \log a - \log b$

$\longrightarrow \beta_1 = 10\left(\log \frac{I_2}{I_0} - \log 2\right)$, 3 dB

$$\rightarrow \beta_1 = 10\left(\log \frac{I_2}{I_0} - \log 2\right)$$

$$= \underbrace{10 \log \frac{I_2}{I_0}}_{} - 10 \log 2 \quad \approx 3\text{ dB}$$

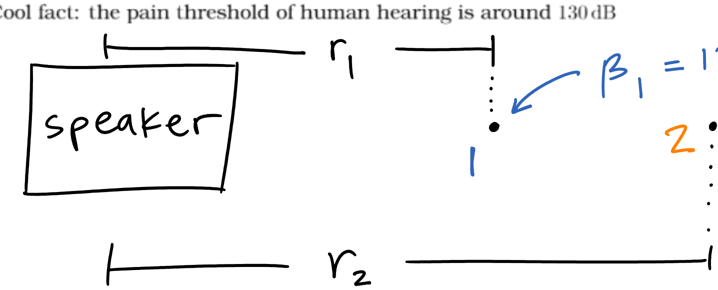
$$\approx \beta_2 - 3 = 95 - 3 = \boxed{92\text{ dB}}$$

Standing Near Concert Speaker

At a rock concert, a dB meter registered 130 dB when placed 2.2 m in front of a loudspeaker on the stage.

- How far away would you have to stand so that the sound level will be a tolerable 85 dB?

  Cool fact: the pain threshold of human hearing is around 130 dB



$$\beta_1 = 130\text{ dB} = 10 \log \frac{I_1}{I_0}$$

$$\beta_2 = 85\text{ dB} = 10 \log \frac{I_2}{I_0}$$

UNKNOWN VARIABLES: I_1, I_2, r_2

WE KNOW $I \propto \frac{1}{r^2}$, SO WE CAN WRITE A RATIO

$$\frac{I_1}{I_2} = \frac{\frac{1}{r_1^2}}{\frac{1}{r_2^2}} = \frac{r_2^2}{r_1^2} \longrightarrow I_1 = \left(\frac{r_2}{r_1}\right)^2 I_2$$

$$\beta_1 = 10 \log \frac{I_1}{I_0} = 10 \log \left[\frac{I_2}{I_0} \left(\frac{r_2}{r_1}\right)^2 \right]$$

RECALL: $\log [a \cdot b] = \log a + \log b$

$$\beta_1 = 10\left(\log\left[\frac{I_2}{I_0}\right] + \log\left[\left(\frac{r_2}{r_1}\right)^2\right]\right)$$

$$= \underbrace{10 \log \frac{I_2}{I_0}}_{} + 2 \cdot 10 \log \frac{r_2}{r_1}$$

$$= 10 \log \underbrace{\frac{I}{I_0}} + 2 \cdot 10 \log \frac{r}{r_1}$$

$$= \beta_2 + 20 \log \frac{r_2}{r_1}$$

SOLVING FOR r_2

$$20 \log \frac{r_2}{r_1} = \beta_1 - \beta_2$$

$$\log \frac{r_2}{r_1} = \frac{\beta_1 - \beta_2}{20} = \frac{130 - 85}{20} = 2.25$$

$$\frac{r_2}{r_1} = 10^{2.25} \longrightarrow r_2 = r_1 \cdot 10^{2.25}$$

$$= (2.2)\, 10^{2.25}$$

$$\boxed{= 391 \text{m}}$$

Moving Firetruck Siren

A firetruck sounding a siren with a frequency of 1280 Hz (f_{SRC}) is traveling at 120.0 km/h. $= 33.3 \ \text{m/s}$

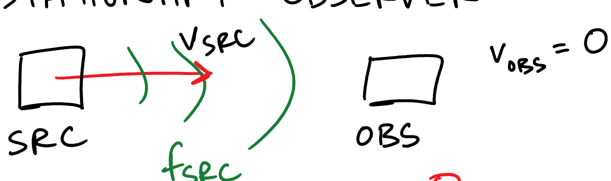
(a) What frequencies does a (stationary) observer standing next to the road hear as the firetruck approaches and as it recedes?

(b) What frequencies does an observer sitting in a car moving at 90 km/h in the the opposite direction hear before and after passing the firetruck?

SRC = SOURCE

OBS = OBSERVER

(a) STATIONARY OBSERVER



(APPROACHING)

$$f_{OBS} = \left[\frac{V \pm V_{OBS}}{V - V_{SRC}} \right] f_{SRC} = \frac{343}{343 - 33.3} \cdot (1280) = \boxed{1418 \text{ Hz}}$$

0

SMALLER DISTANCE $\xrightarrow{\text{IMPLIES}}$ HIGHER OBS. FREQ $\xrightarrow{\text{REQUIRES}}$ SMALL DENOMINATOR!!

$$f_{OBS} = \left[\frac{V \pm \cancel{V_{OBS}}^{\,0}}{V + V_{SRC}}\right] f_{SRC} = \frac{343}{343+33.3} \cdot 1280 = \boxed{1167 \text{ Hz}}$$

INCREASING DISTANCE $\xrightarrow{\text{IMPLIES}}$ LOWER OBS. FREQUENCY $\xrightarrow{\text{REQUIRES}}$ BIG DENOMINATOR !!

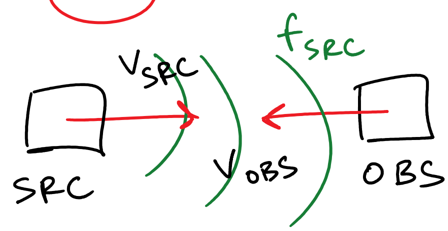
Moving Firetruck Siren

A firetruck sounding a siren with a frequency of 1280 Hz ($= f_{SRC}$) is traveling at 120.0 km/h ($= 33.3$ m/s).

(a) What frequencies does a (stationary) observer standing next to the road hear as the firetruck approaches and as it recedes?

(b) What frequencies does an observer sitting in a car moving at 90 km/h ($= 25$ m/s) in the the opposite direction hear before and after passing the firetruck?

(b) APPROACHING

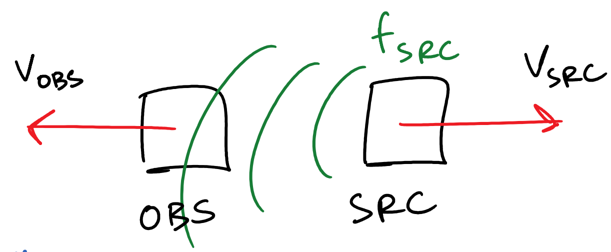


DECREASING DISTANCE

$$f_{OBS} = \frac{V + V_{OBS}}{V - V_{SRC}} \cdot f_{SRC} = \frac{343 + 25}{343 - 33.3} \cdot 1280 = \boxed{1521 \text{ Hz}}$$

DECREASING DISTANCE

RECEDING :



INCREASING DISTANCE

$$f_{OBS} = \frac{V - V_{OBS}}{V + V_{SRC}} \, f_{SRC} = \frac{343 - 25}{343 + 33.3} \cdot 1280 = \boxed{1082 \text{ Hz}}$$

INCREASING DISTANCE

NOTE: There are many ways to determine the sign of the numerator and denominator. The way presented here is based on looking at whether the distance increases or decreases; and then picking the proper sign that corresponds to the higher or lower observed frequency.

For example, in the very last f_obs equation:

- For the observer (numerator), we see that the observer's motion increases the distance; which then leads to a lower observed frequency. In order to have a lower f_obs, we need to have a small numerator; therefore minus sign in numerator .
- For the source (denominator), we see that the source's motion increases the distance; which then leads to a lower observed frequency. In order to have a lower f_obs, we need to have a big denominator; therefore plus sign in denominator.