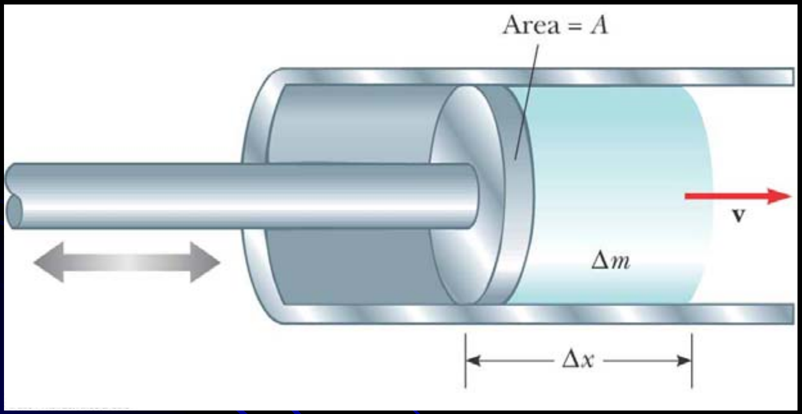
17.3 Intensity of periodic sound waves

The Intensity I of a sound wave is defined to be the average rate per unit area at which energy is transmitted by the wave. The intensity I is related to the displacement amplitude s_{max} by

$$\boxed{I = P/A = \tfrac{1}{2}(\rho\, v\, \omega^2\, s_{max}^{\ 2}) \quad [\ \mathrm{W/m^2}\ ]}$$

- **Derivation of intensity *I* :**



Total energy : $E_\lambda = K_\lambda + U_\lambda$

$= \tfrac{1}{2}\, \rho\, A\, \lambda\, (\omega\, s_{max})^2$

Power : $P = E_\lambda / T$

$= \tfrac{1}{2}\, \rho\, A\, v\, (\omega s_{max})^2$

Intensity : $I = P/A$

$= \tfrac{1}{2}\, \rho\, v\, (\omega s_{max})^2$

The Intensity I of a sound wave :

$$\boxed{I = \tfrac{1}{2}(\rho\, v\, \omega^2\, s_{max}{}^2) \quad [\ \mathrm{W/m^2}\ ]}$$

- **Sound level β in Decibels (dB)**

$$\boxed{\beta = (10\ \mathrm{dB}) \log (I / I_0)}$$

where the constant I_0 is the reference intensity ($I_0 = 10^{-12}$ W/m^2).

Sound Levels

Source of Sound	β (dB)
Nearby jet airplane	150
Jackhammer; machine gun	130
Siren; rock concert	120
Subway; power mower	100
Busy traffic	80
Vacuum cleaner	70
Normal conversation	50
Mosquito buzzing	40
Whisper	30
Rustling leaves	10
Threshold of hearing	0

- **Spherical and plane waves**

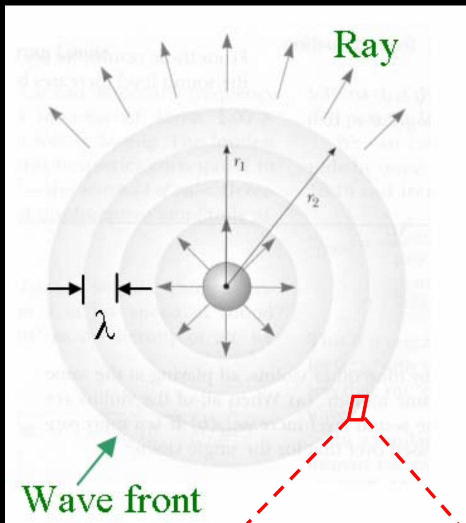
(*i*) Spherical wave : Wave intensity I at a distance r from the source is

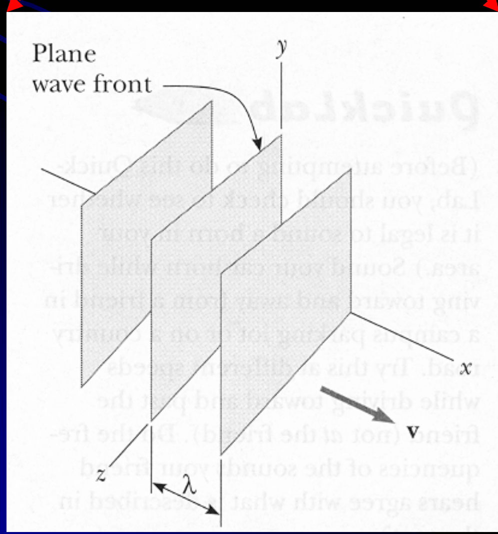
$$I = P_{av} / A$$
$$= \boxed{P_{av} / (4\pi r^2)}$$

where P_{av} = average power emitted by the source, and $4\pi r^2$ = area of spherical surface.

$$\therefore \boxed{I \propto 1 / r^2}$$

i.e., the wave intensity decreases in proportion to the square of the distance from the source.





(*ii*) Plane wave :

A small portion of a spherical wave far from its source can be considered a plane wave.

17.4 The Doppler Effect

The frequency change of the sound wave caused by the motion of the receiver (or by motion of the source).

- **Calculate the change in frequency in three different cases:**

(1) Source moving & Observer stationary.

$f' = f/(1 - v_s/v)$ [source moving toward stationary observer]

(2) Observer moving & Source stationary.

$f' = f(1 + v_o/v)$ [observer moving toward source]

(3) Observer and source both moving.

$f' = f[(v + v_o) / (v - v_s)]$ [observer moving toward moving source]

- General equation :

$$f_o' = f_s \frac{v + v_o}{v - v_s}$$

v_o and v_s $\begin{cases} + : \text{approaching.} \\ - : \text{receding.} \end{cases}$

$v = 343$ m/s

	observer	source	
	25 m/s	35 m/s	
1.	$\circ\!\longrightarrow$ approaching	$\longleftarrow\!\circ$ approaching	$f_o' = \frac{343+25}{343-35} f_s$
2.	$\circ\!\longrightarrow$ approaching	$\circ\!\longrightarrow$ receding	$f_o' = \frac{343+25}{343-(-35)} f_s$
3.	$\longleftarrow\!\circ$ receding	$\circ\!\longrightarrow$ receding	$f_o' = \frac{343+(-25)}{343-(-35)} f_s$
4.	$\longleftarrow\!\circ$ receding	$\longleftarrow\!\circ$ approaching	$f_o' = \frac{343+(-25)}{343-(35)} \cdot f_s$