

Sound Pressure

When sound passes through a medium (fluid), there is a change in volume as follows:

$$\frac{dv}{V} = \lim_{\Delta x \rightarrow 0} \frac{S(y(x + \Delta x, t) - y(x, t))}{S\Delta x}$$
$$\frac{dv}{V} = \frac{\delta y(x, t)}{\delta x}$$

Note that the bulk modulus B is represented in terms of pressure and change in volume:

$$B = \frac{-p(x, t)}{\frac{dv}{V}}$$

These two equations can then be combined and rearranged to get the pressure equation:

$$p(x, t) = BkA \sin(kx - \omega t)$$

where B is the bulk modulus.

The maximum pressure can then be found through:

$$p_{\max} = BkA \quad (\text{of a sinusoidal sound wave})$$

Sound Velocity

We can express velocity in terms of the Bulk or Young's Modulus.

For liquids

$$v = \sqrt{\frac{B}{\rho}}$$

For solids

$$v = \sqrt{\frac{B}{\rho}}$$

We can also find the velocity in gas in terms of the heat capacity ratio γ :

$$v = \sqrt{\frac{\gamma RT}{M}}$$

where:

- T = absolute temperature (K)
- M = molar mass
- R = gas constant, 8.314 J/mole-K
- γ = heat capacity ratio

Sound Intensity

The intensity of a sound wave can be expressed as follows:

$$I = \frac{1}{2} \sqrt{\rho B} \omega^2 A^2$$

$$I = \frac{p_{\max}^2}{2\rho v} = \frac{p_{\max}^2}{2\sqrt{\rho B}}$$

Then to get the sound intensity level in decibels:

$$\beta = (10dB) \log \frac{I}{I_0}$$

where $I_0 = 1 \times 10^{-12} W/m^2$

Standing Sound Wave

Open Pipe (Open both sides)

$$f_n = n \frac{v}{2L} \quad (n = 1, 2, 3, \dots)$$

Stopped Pipe (Closed one side)

$$f_n = n \frac{v}{4L} \quad (n = 1, 3, 5, \dots)$$

Their fundamental frequencies would then be:

$$f_1 = \frac{v}{2L} \quad (\text{for an open pipe})$$

$$f_1 = \frac{v}{4L} \quad (\text{for a closed pipe})$$

Beat Frequency

The frequency of a "beat" is:

$$f_{\text{beat}} = |f_2 - f_1|$$

Doppler Effect & Shock Wave

Doppler Effect

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

Shock Wave

$$\sin \alpha = \frac{vt}{v_s t} = \frac{v}{v_s}$$

where the sign of v_L and v_s depends on the direction of the movement of the listener and source. When moving towards the other, then the velocity is a positive. If moving away from the other, then the velocity is a negative.