Velocity of Sound in Elastic Medium.

When a sound wave travels through a medium such as air, water or steel, it will set particles of medium into vibration as it passes through it. For this to happen the medium must possess both inertia i.e. mass density (so that kinetic energy may be stored) and elasticity (so that PE may be stored). These two properties of matter determine the velocity of sound.

i.e. velocity of sound is the characteristic of the medium in which wave propagate.

$v = \sqrt{\frac{E}{\rho}}$ (E = Elasticity of the medium; ρ = Density of the medium)

Important points

(1) As solids are most elastic while gases least i.e. $E_S > E_L > E_G$. So the velocity of sound is maximum in solids and minimum in gases

vsteel>vwater>vair

5000 m/s > 1500 m/s > 330 m/s

As for sound vwater>vAir while for light vw<vA.

Water is rarer than air for sound and denser for light.

The concept of rarer and denser media for a wave is through the velocity of propagation (and not density). Lesser the velocity, denser is said to be the medium and vice-versa.

(2) Newton's formula: He assumed that when sound propagates through air temperature remains constant.(i.e. the process is isothermal) vair = $\sqrt{\frac{K}{\rho}} = \sqrt{\frac{P}{\rho}}$ As K = Eθ = P ; Eθ = Isothermal elasticity; P = Pressure.

By calculation vair = 279 m/sec.

However the experimental value of sound in air is 332 m/sec which is greater than that given by Newton's formula.

(3) Laplace correction: He modified Newton's formula assuming that propagation of sound in air as adiabatic process.

v = $\sqrt{\frac{k}{\rho}}$ = $\sqrt{\frac{E_\phi}{\rho}}$ (As k = $E_\phi = \gamma P$ = Adiabatic elasticity)

v = $\sqrt{1.41}$ × 279= 331.3 m/s ($\gamma_{Air} = 1.41$)

(4) Effect of density: v = $\sqrt{\frac{\gamma P}{\rho}}$. v $\propto \frac{1}{\sqrt{\rho}}$

(5) Effect of pressure: $v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma R T}{M}}$. Velocity of sound is independent of the pressure of gas provided the temperature remains constant. ($P \propto \rho$ When T = constant)

(6) Effect of temperature: $v = \sqrt{\frac{\gamma RT}{M}}$. $v \propto \sqrt{T(\text{in } K)}$

When the temperature change is small then vt = v0 (1 + α t)

v0 = velocity of sound at 0°C, vt = velocity of sound at t°C , α = temp-coefficient of velocity of sound.

Value of α = 0.608 $\frac{m/s}{^oC}$ = 0.61 (Approx.)

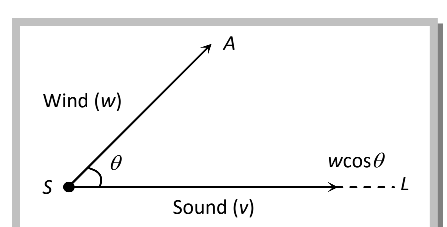
Temperature coefficient of velocity of sound is defined as the change in the velocity of sound, when temperature changes by 1°C.

(7) Effect of humidity: With increase in humidity, density of air decreases. So with rise in humidity velocity of sound increases.

This is why sound travels faster in humid air (rainy season) than in dry air (summer) at the same temperature.

(8) Effect of wind velocity : Because wind drifts the medium (air) along its direction of motion therefore the velocity of sound in a particular direction is the algebraic sum of the velocity of sound and the component of wind velocity in that direction. Resultant velocity of sound along SL = v + w cosθ.

(9) Sound of any frequency or wavelength travels through a given medium with the same velocity.



(v = constant) For a given medium velocity remains constant. All other factors like phase, loudness pitch, quality etc. have practically no effect on sound velocity.

(10) Relation between velocity of sound and root mean square velocity.

vsound = $\sqrt{\frac{\gamma RT}{M}}$ and vrms = $\sqrt{\frac{3RT}{M}}$ so $\frac{v_{rms}}{v_{sound}}$ = $\sqrt{\frac{3}{\gamma}}$ or vsound = [γ /3]1/2 vrms.

(11) There is no atmosphere on moon, therefore propagation of sound is not possible there. To do conversation on moon, the astronaut uses an instrument which can transmit and detect electromagnetic waves.