Chapter 17 Sound

Sound waves are longitudinal waves characterized by density or pressure fluctuations.

Audible sound, that our ears can detect, ranges in frequency from about 20 Hz to 20,000 Hz.

Infrasonic: frequencies below 20 Hz, e.g. earthquake, thunder, etc.

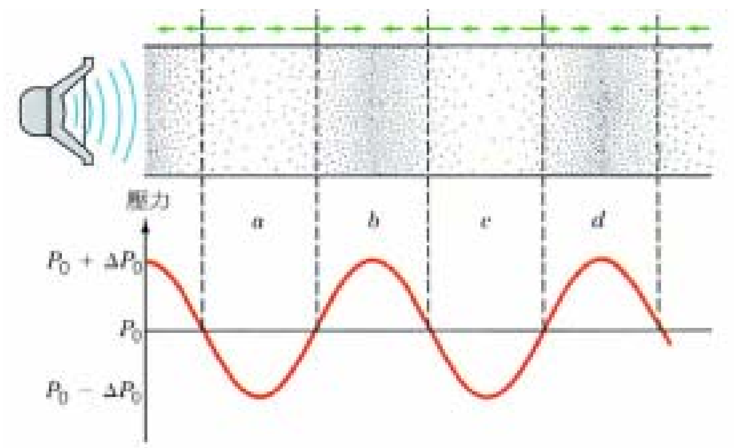
Ultrasonic: frequencies above 20,000 Hz. Could be heard by cats, dogs, bats, and porpoises. Application: sonar

Why not use EM wave to detect submarine? What is the advantage of sound wave?

17.1 Wave Characteristics

How to generate sound waves? Compression and rarefaction.

Compression is an increase in pressure above the equilibrium value P_o, and ***rarefaction*** is a decrease in pressure below P_o.



In the equilibrium state the pressure and density in a fluid are uniform, but are not at rest.

Speed of Longitudinal Waves in a Fluid

The speed of a longitudinal waves in a fluid is given by

$$v = \sqrt{\frac{B}{\rho}}$$ where B is the bulk modulus.

Example 17.1: Calculate the speed of longitudinal waves in water and in air. (water: $B=2.1\times10^9$ N/m^2, $\rho=1000$ kg/m^3; air: $B=1.41\times10^5$ N/m^2, $\rho=1.29$ kg/m^3)

Sol:

(a) v=1500 m/s

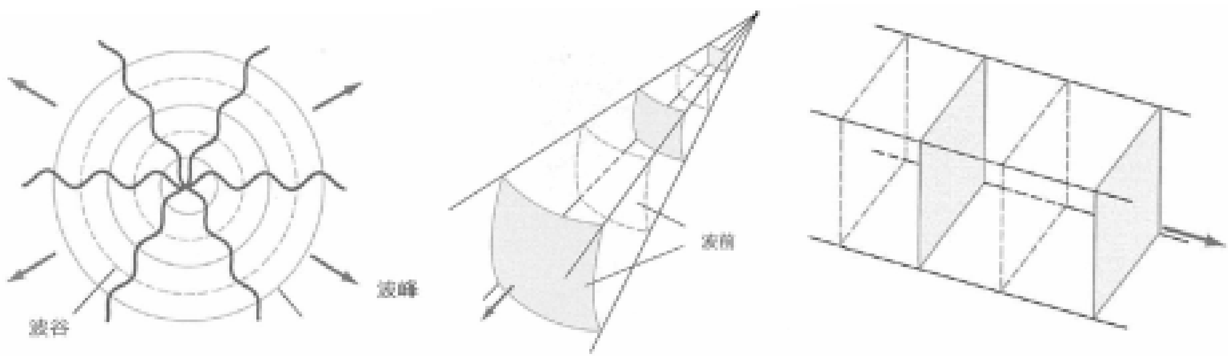
(b) v=330 m/s

What is the difference when speaking at two extreme condition very hot (373 k) and very cold (273 k)?

Wave Front

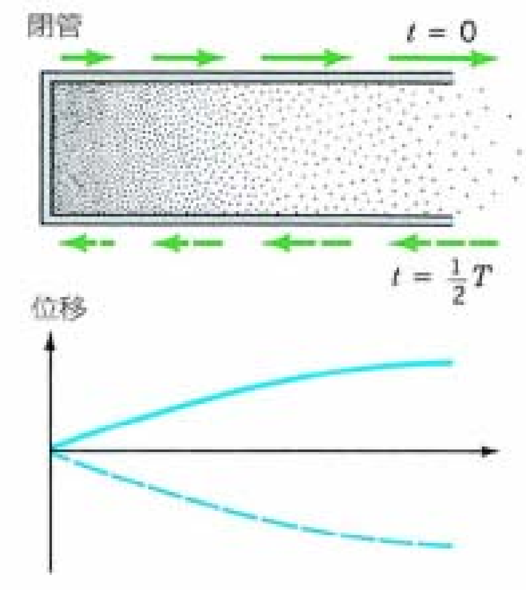
In discussing the propagation of two-dimensional or three-dimensional waves, it is useful to introduce the concept of a ***wave front***.

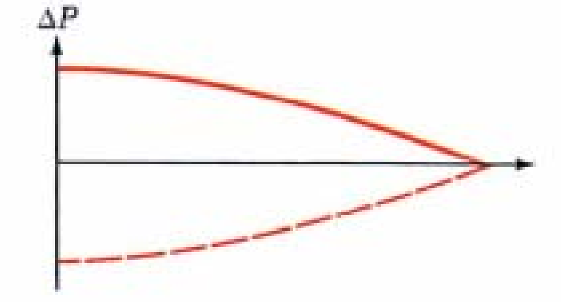
In general, a wave front is a locus of points *at which the wave function has* ***the same phase***.



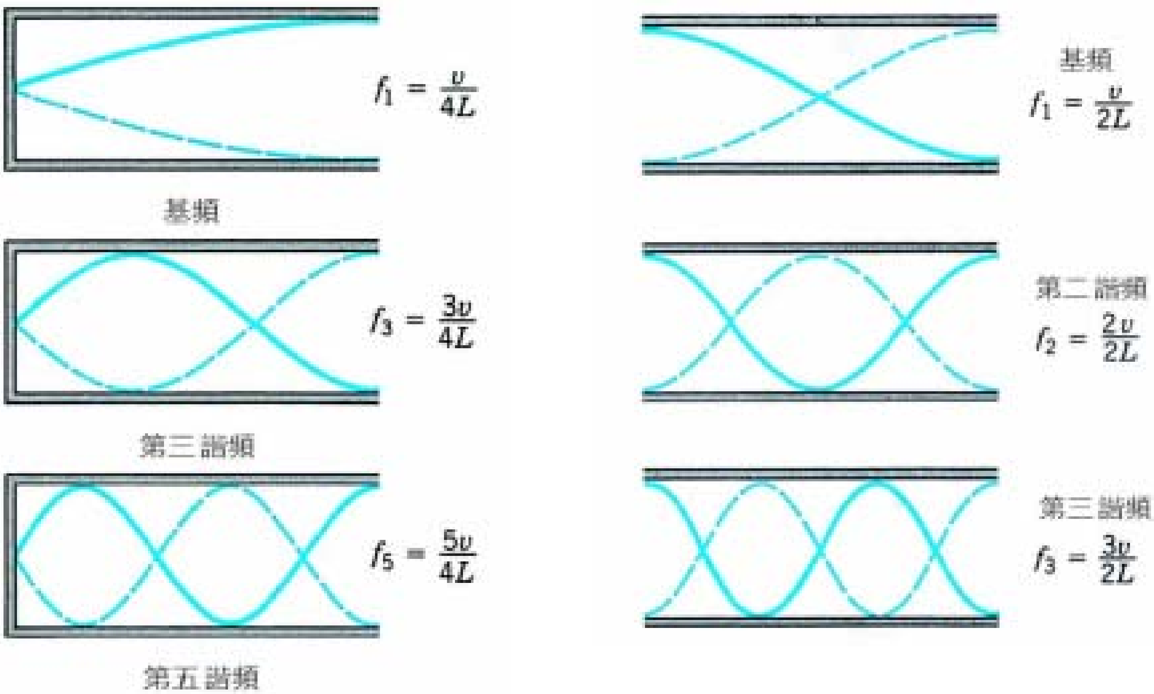
17.2 Resonant Standing Sound Waves

Resonant standing waves can be produced in air columns, for example, in organ pipes, flutes, and other woodwind instrument, because the sound wave are ***reflected*** both at a closed end and at an open end of a pipe.





Discrete Resonant Waves in Closed and Open Pipes



17.3 The Doppler Effect

In 1842, Doppler published paper in which he tried to relate the colors of stars to their motion. Although this idea was *incorrect*, he did analyze a similar phenomenon for sound waves.

The change in the observed frequency of a wave when there is relative motion between the source and an observer is called the **Doppler effect**.

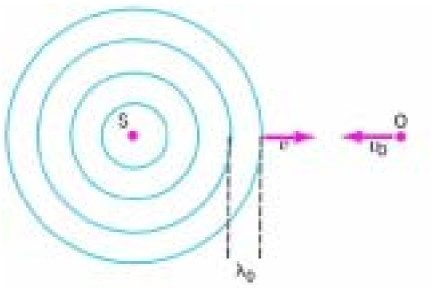
The medium (air) acts as an "***absolute***" reference frame that allows us to distinguish whether the source and/or the observer is moving.

What happens when the medium is moving? ***Extra bonus***.

The Doppler Effect (II)

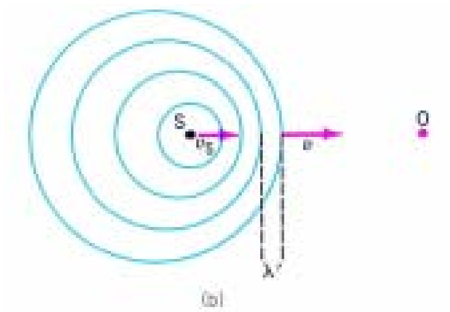
(a) Source at rest, observer moves
(velocity modulation)

$$f' = \frac{v'}{\lambda_o} = \frac{v \pm v_o}{v} f_o$$



(b) Source moves, observer at rest
(wavelength modulation)

$$f' = \frac{v}{\lambda'} = \frac{v}{v \pm v_s} f_o$$



All four possibilities can be combined into one equation:

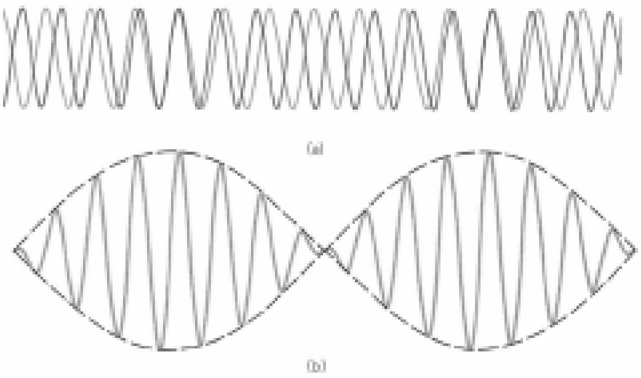
$$f' = \frac{v'}{\lambda'} = \frac{v \pm v_o}{v \pm v_s} f_o$$

17.4 Interference in Time: Beats

When two waves of slightly different frequencies are superposed. The resulting disturbance varies *periodically in amplitude*.

$$y = y_1 + y_2 = A\sin(2\pi f_1 t) + A\sin(2\pi f_2 t)$$
$$= 2A\cos[2\pi(\frac{f_1 - f_2}{2})t]\sin[2\pi(\frac{f_1 + f_2}{2})t]$$

Beat frequency (|f1-f2|): frequency of the amplitude envelope



17.5 Velocity of Longitudinal Waves in a Fluid

Newton's second law applied to the motion of the element is

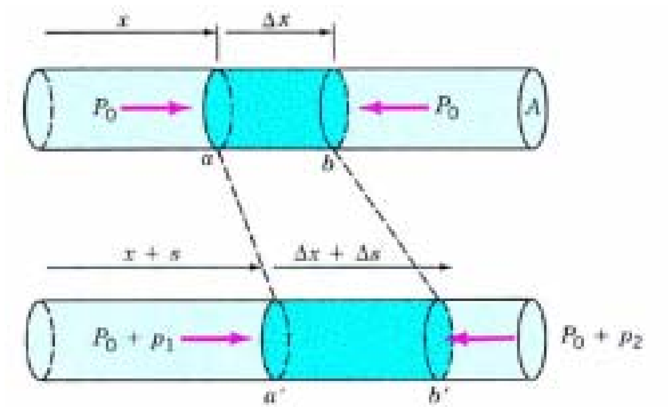
$$(p_1 - p_2)A = (\rho A \Delta x)\frac{\partial^2 s}{\partial t^2}$$

$$\frac{\partial p}{\partial x} = -\rho \frac{\partial^2 s}{\partial t^2}$$

$$B = -\Delta p/(\Delta V/V)$$

$$\Delta p = -B\frac{\partial s}{\partial x}$$

$$\frac{\partial^2 s}{\partial x^2} = \frac{\rho}{B}\frac{\partial^2 s}{\partial t^2}$$



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

17.6 Sound Intensity

Consider a harmonic sound wave propagating along a tube of cross-sectional area A, as shown in Fig. 17.13. The quantity p is the excess pressure caused by the wave, and ds/dt is the velocity of an element of the fluid.

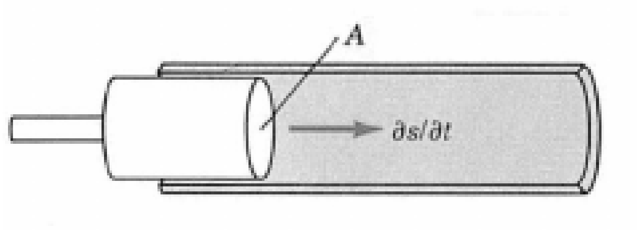
The instantaneous power supplied by the wave to the element is

$$P = Fv = pA\frac{\partial s}{\partial t}$$

$$p = -p_o \cos(kx - \omega t)$$

$$\frac{\partial s}{\partial t} = -s_o \omega \cos(kx - \omega t)$$

$$P = p_o A s_o \omega \cos^2(kx - \omega t)$$



Intensity Level: The Decibel Scale

The intensity of a sound is perceived by the ear as the subjective sensation of loudness.

Intensity level β:

$$\beta = 10\log\frac{I}{I_o}$$

$$= 10\log\left(\frac{?\ \mathrm{W/m^2}}{10^{-12}\ \mathrm{W/m^2}}\right)$$

表 17.1 強度級（dB）

強度級	（dB）
剛好聽到	0
落葉沙沙聲	10
寧靜的大廳	25
辦公室	60
交談	60
繁忙的交通 (3 m)	80
大聲的古典樂	95
大聲的搖滾樂	120
噴射引擎 (20 m)	130

Exercises and Problems

Ch.17:

Ex. 11, 27, 35, 42, 43, 49

Prob. 1, 3, 9