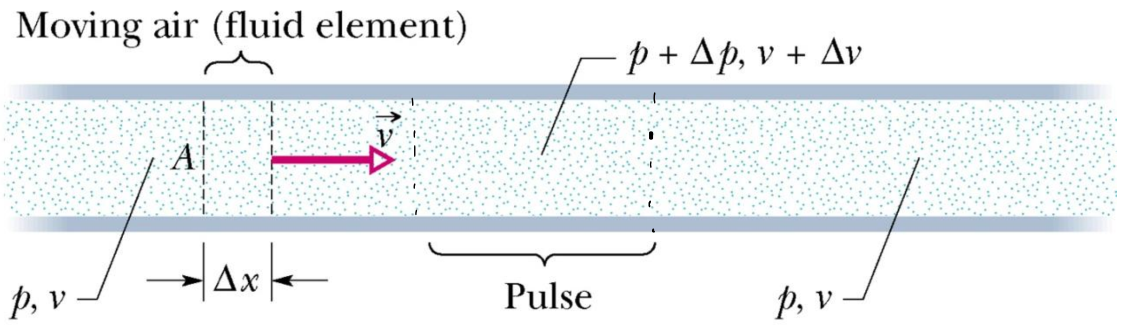
# Copyright statement

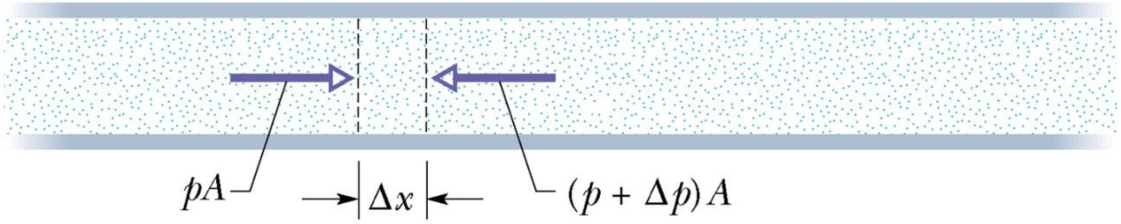
- The images and the pictures in this lecture are provided by the CDs accompanied by the books
  1. University Physics, Bauer and Westfall, McGraw-Hill, 2011.
  2. Principles of Physics, Halliday, Resnick, and Walker, Wiley, 8th and 9th Ed.
- The rest is made by me.

# Chap. 16 Sound

# The speed of sound




(a)




(b)

$$F = pA - (p + \Delta p)A = -\Delta pA$$

$$\Delta m = \rho \Delta V = \rho A \Delta x = \rho A v \Delta t$$

$$a = \frac{\Delta v}{\Delta t}$$

$$-\Delta pA = (\rho A v \Delta t)\frac{\Delta v}{\Delta t}$$

$$\rho v^2 = -\frac{\Delta p}{\Delta v / v}$$

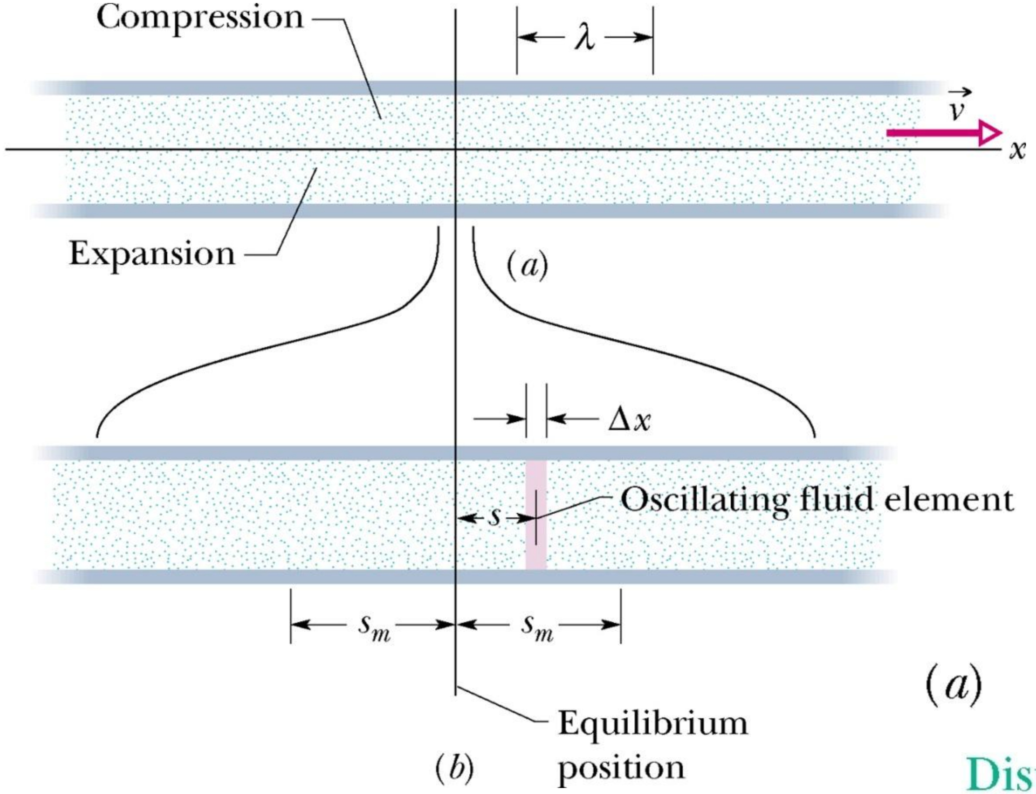
$$\frac{\Delta V}{V} = \frac{A \Delta v \Delta t}{A v \Delta t} = \frac{\Delta v}{v}$$

$$\rho v^2 = -\frac{\Delta p}{\Delta v / v} = -\frac{\Delta p}{\Delta V / V} = B$$

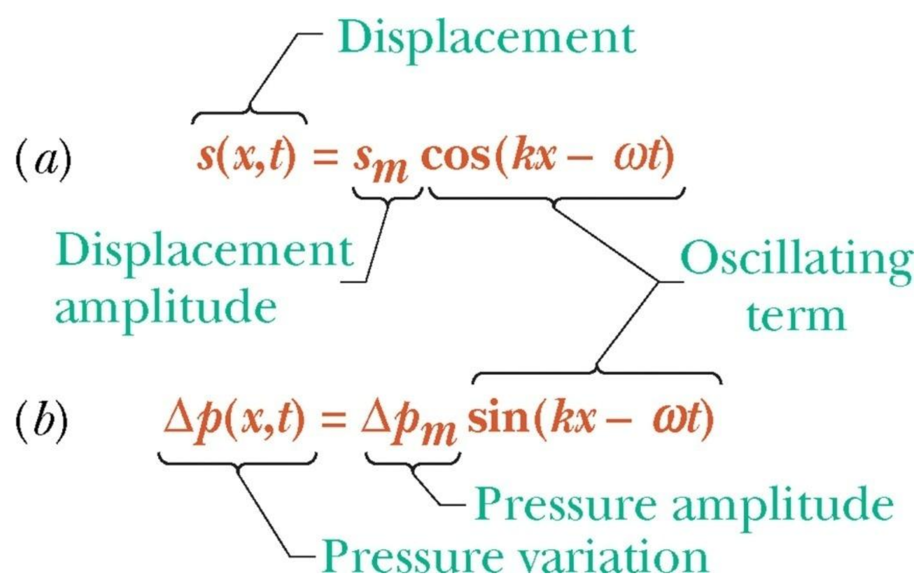
$$v = \sqrt{\frac{B}{\rho}}$$

$$v = \sqrt{\frac{\tau}{\mu}}$$

# Traveling sound waves




$$s(x,t) = s_m \cos(kx - \omega t)$$




$$\Delta p_m = (v\rho\omega)s_m$$

$$\Delta p = -B\frac{\Delta V}{V}$$

$$V = A\Delta x,\ \Delta V = A\Delta s \qquad \Delta p = -B\frac{\Delta s}{\Delta x} = -B\frac{\partial s}{\partial x}$$

$$\frac{\partial s}{\partial x} = \frac{\partial}{\partial x}[s_m \cos(kx - \omega t)] = -ks_m \sin(kx - \omega t)$$

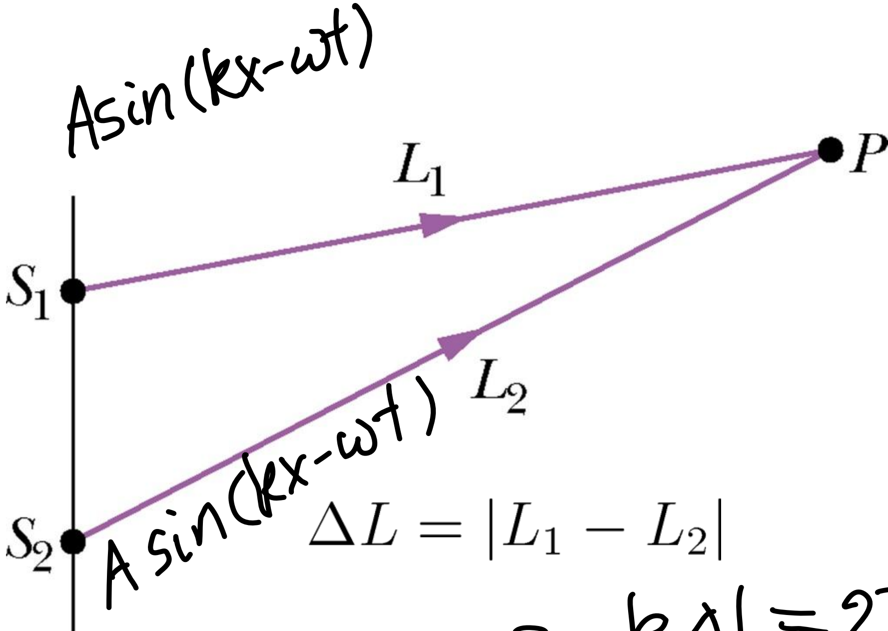
$$\Delta p = Bks_m \sin(kx - \omega t) = \Delta p_m \sin(kx - \omega t)$$

$$\Delta p_m = Bks_m = \rho v^2 ks_m = (v\rho\omega)s_m$$

$$v = \frac{\omega}{k} \qquad \rho v \frac{\omega}{k} k s_m = \rho v \omega s_m$$

# Interference

$$\Delta\phi = \frac{2\pi}{\lambda}\Delta L$$




$$\frac{\Delta\phi}{2\pi} = \frac{\Delta L}{\lambda}$$

$$\frac{\Delta\phi}{2\pi} = \frac{\Delta L}{\lambda}$$

$$\phi = \frac{\Delta L}{\lambda} 2\pi$$

$$\Delta L = |L_1 - L_2|$$

$$k\Delta L = 2\pi m = \frac{2\pi}{\lambda}\Delta L = \Delta\phi$$

완전보강간섭 $\phi = 2\pi m \ (m = 0, 1, 2, \cdots)$ $\quad \frac{\Delta L}{\lambda} = 0, 1, 2, \cdots$

완전상쇄간섭 $\phi = (2m+1)\pi, \ (m = 0, 1, 2, \cdots)$

$$\frac{\Delta L}{\lambda} = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \cdots$$

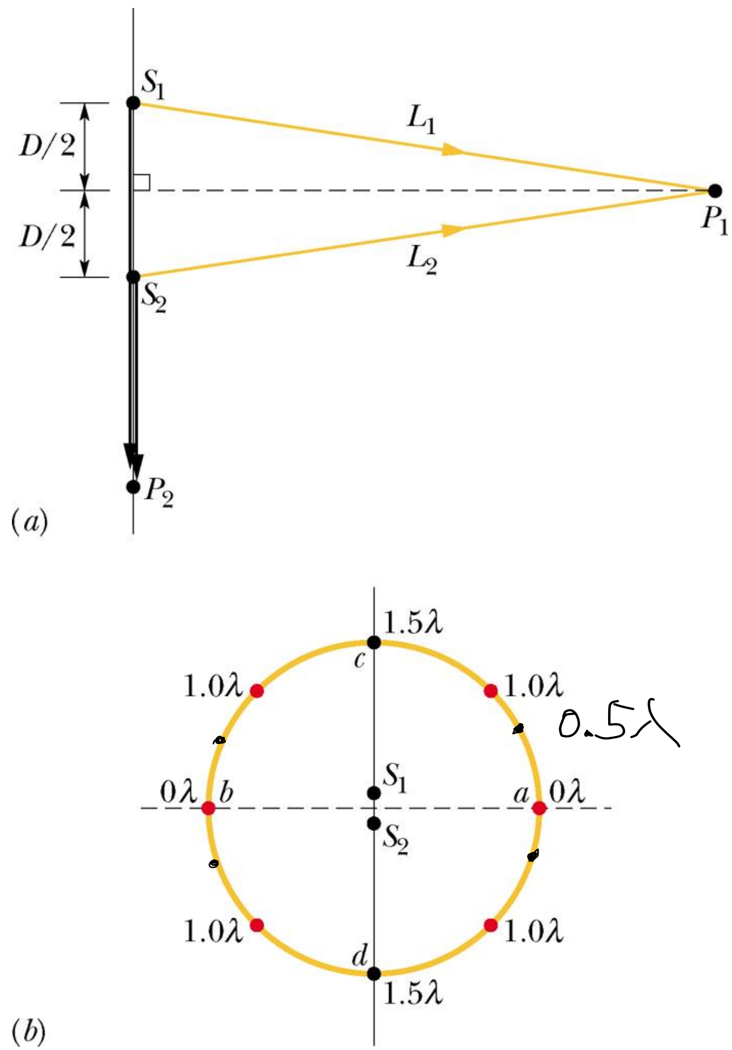
$f = 3400$ Hz

$v = 340$ m/s

$\lambda = \frac{v}{f} = \frac{340}{3400}$

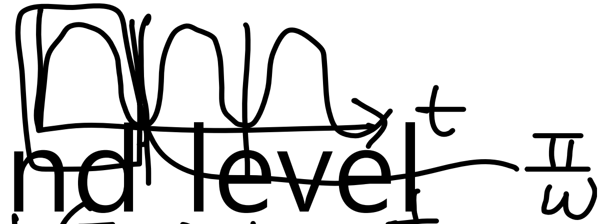
# Sample prob.

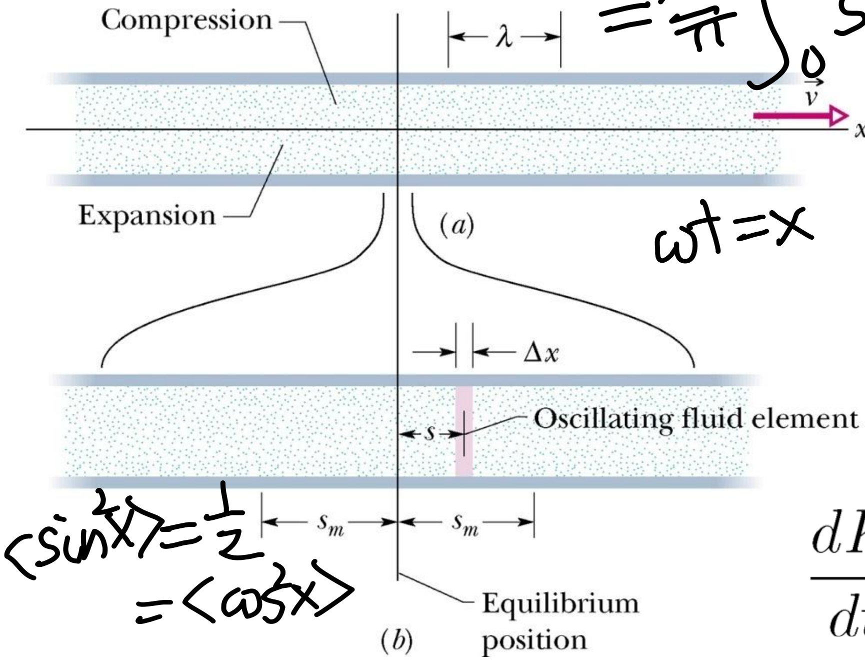
$D = \frac{3}{2}\lambda$



# Intensity and sound level

$\langle \sin^2\omega t \rangle_{av} = \frac{\omega}{\pi}\int_0^{\pi/\omega} \sin^2\omega t\,dt = \frac{\omega}{\pi}\int_0^{\pi} \sin^2 x \frac{dx}{\omega} = \frac{1}{\pi}\int_0^{\pi} \sin^2 x\,dx = \frac{1}{2}$






$\omega t = x$

$\langle \sin^2 x \rangle = \frac{1}{2} = \langle \cos^2 x \rangle$

$$dK = \frac{1}{2} dm v_s^2$$

$$v_s = \frac{\partial s}{\partial t} = \omega s_m \sin(kx - \omega t)$$

$$dK = \frac{1}{2}(\rho A dx)(\omega s_m)^2 \sin^2(kx - \omega t)$$

$$\frac{dK}{dt} = \frac{1}{2}\rho A v \omega^2 s_m^2 \sin^2(kx - \omega t)$$

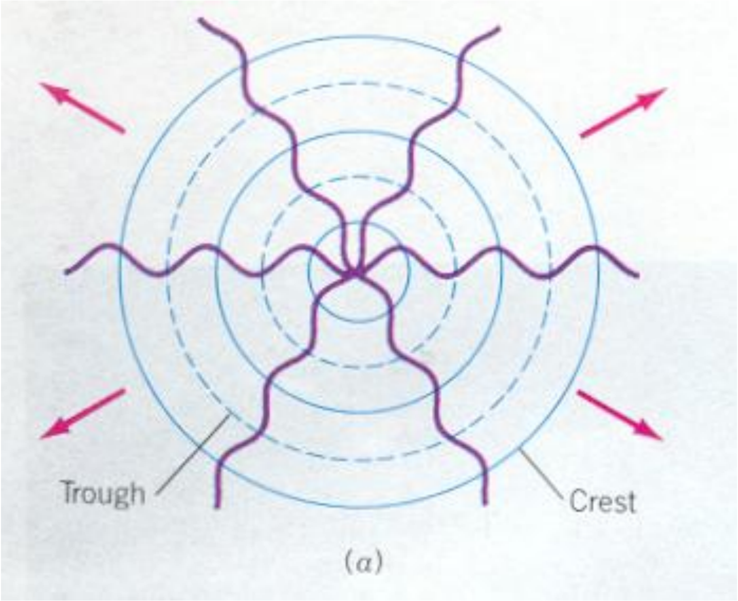
$$\left(\frac{dK}{dt}\right)_{\text{avg}} = \frac{1}{2}\rho A v \omega^2 s_m^2 \left[\sin^2(kx - \omega t)\right]_{\text{avg}} = \frac{1}{4}\rho A v \omega^2 s_m^2$$

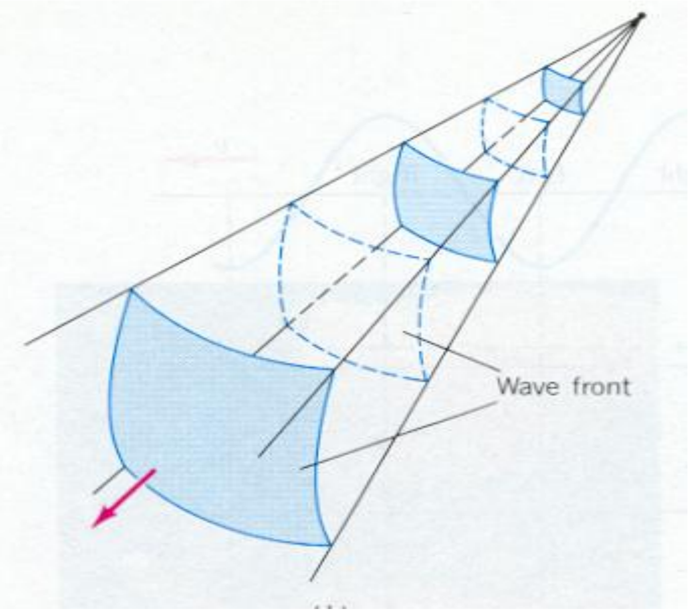
$\frac{1}{2}\rho A v \omega^2 s_m^2 = \frac{dE}{dt} = P$

소리의 세기 $$I = \frac{P}{A} = \frac{2(dK/dt)_{\text{avg}}}{A} = \frac{1}{2}\rho v \omega^2 s_m^2$$

$$\beta = (10\ \text{dB}) \log \frac{I}{I_0} \qquad I_0 = 10^{-12}\ \text{W/m}^2$$

# 거리에 따른 세기의 변화




소리의 세기

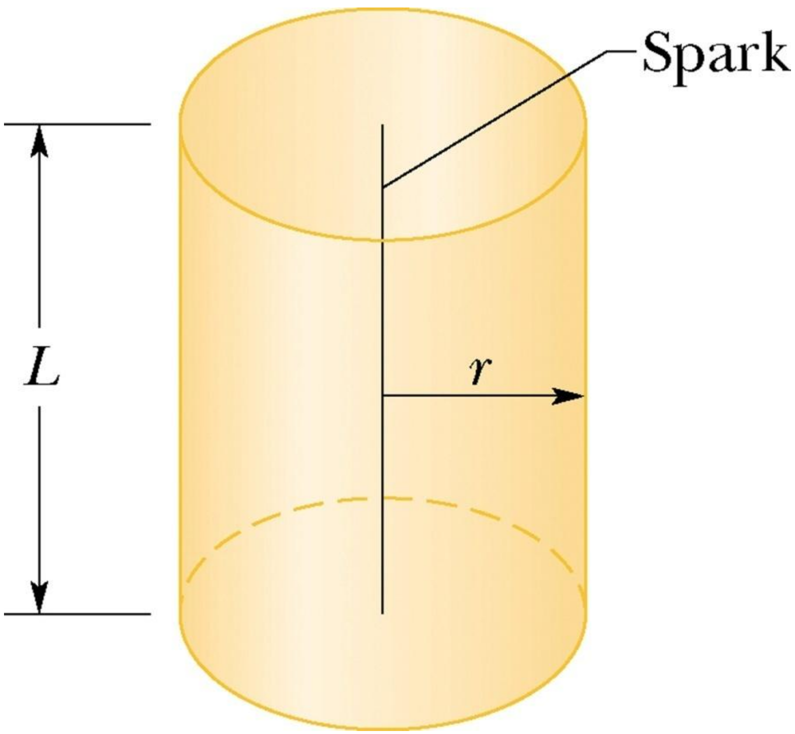
$$I = \frac{P}{4\pi r^2} \propto r^{-2}$$

소리의 진폭

$$I = \tfrac{1}{2}\rho v \omega^2 s_m^2 = \frac{P}{4\pi r^2}$$

$$\therefore s_m = \sqrt{\frac{P}{2\pi \rho v \omega^2}}\frac{1}{r} \propto r^{-1}$$

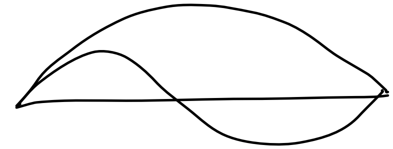
# Sample prob.

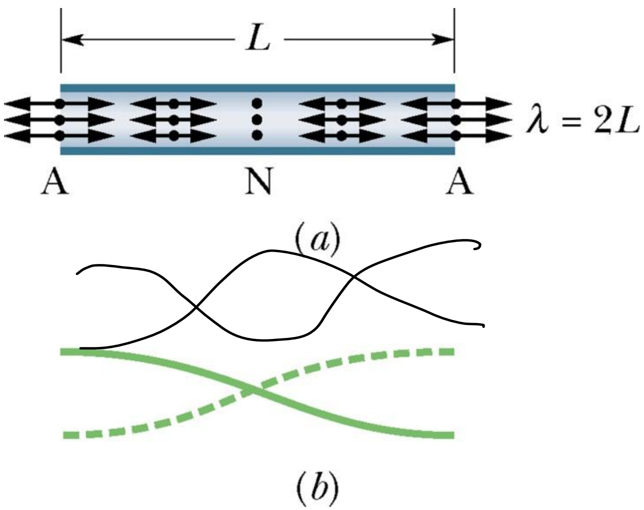



$$I = \frac{P}{A} = \frac{P_s}{2\pi r L}$$

$L = 10 \text{ m},\ P_s = 1.6 \times 10^4 \text{ W}$

# Musical source






$$\lambda = \frac{2L}{n}, (n = 1, 2, 3, \cdots)$$

$L = \frac{\lambda}{2} n$

n: harmonic number
(number of nodes)

$\lambda = \frac{2L}{n}$

$$f = \frac{v}{\lambda} = \frac{nv}{2L}, (n = 1, 2, 3, \cdots)$$

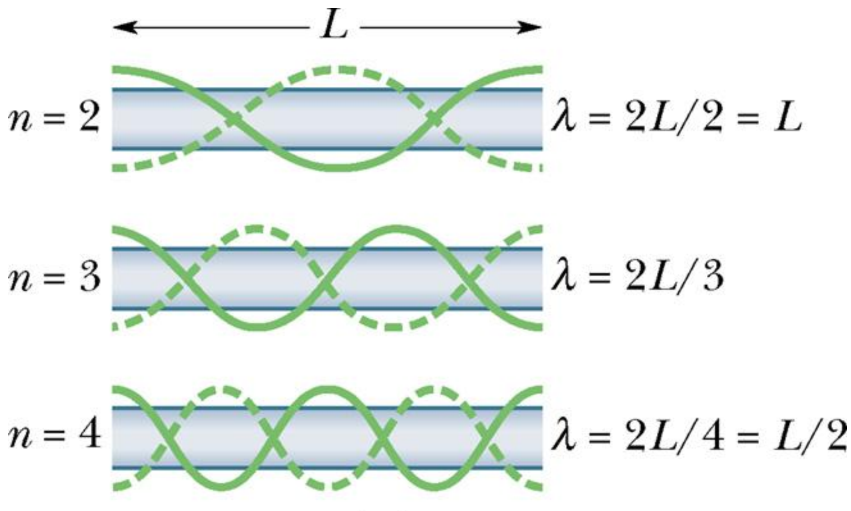
First harmonic

$= \frac{n}{2L}\sqrt{\frac{B}{\rho}}$

$L = \frac{\lambda}{2} n$

$n = 1, 2, 3, \cdots$

$f = \frac{n}{2L}\sqrt{\frac{T}{\mu}}$ string



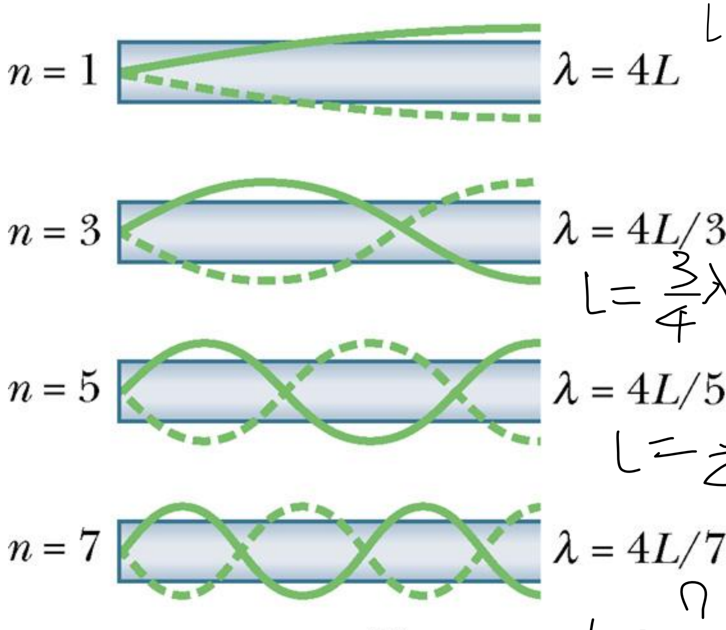

(a)

양 끝이 열린 관

$$f = \frac{v}{\lambda} = \frac{nv}{2L}, (n = 1, 2, 3, \cdots)$$

$L = \frac{\lambda}{2} n \quad \lambda = \frac{2L}{n}$

$f = \frac{v}{\lambda} = \frac{vn}{2L}$




(b)

$L = \frac{\lambda}{4}$

한 끝이 열린 관

$$\lambda = \frac{4L}{n}, (n = 1, 3, 5, \cdots)$$

$L = \frac{3}{4}\lambda$

$$f = \frac{v}{\lambda} = \frac{nv}{4L}, (n = 1, 3, 5, \cdots)$$

$L = \frac{5}{4}\lambda$

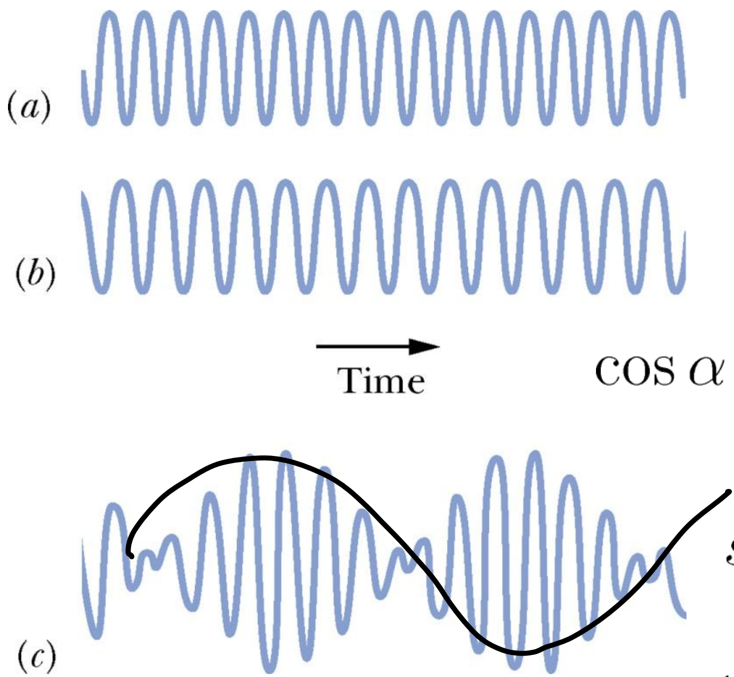
$L = \frac{7}{4}\lambda$

$L = \frac{2n-1}{4}\lambda$

$n = 1, 2, 3, \cdots$

$\lambda = \frac{4L}{2n-1}$ → n

# Beat




$$s_1 = s_m \cos \omega_1 t, \;\; s_2 = s_m \cos \omega_2 t$$

$$s = s_1 + s_2 = s_m(\cos \omega_1 t + \cos \omega_2 t)$$

$$\cos \alpha + \cos \beta = 2 \cos \left[\frac{1}{2}(\alpha - \beta)\right] \cos \left[\frac{1}{2}(\alpha + \beta)\right]$$

$$s = 2s_m \cos \left[\frac{1}{2}(\omega_1 - \omega_2)t\right] \cos \left[\frac{1}{2}(\omega_1 + \omega_2)t\right]$$

$$\omega' = \frac{1}{2}(\omega_1 - \omega_2), \;\; \omega = \frac{1}{2}(\omega_1 + \omega_2)$$

$$s(t) = [2s_m \underline{\cos \omega' t}] \cos \omega t$$

$$\omega_{\text{beat}} = 2\omega' = \omega_1 - \omega_2$$

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

맥놀이 진동수