Announcements

1. Exam 2 corrections – due today
2. Today's lecture

   Comments of some previous HW problems

   Summary of the physics of waves

   The physics of sound

3. HRW6 15.P.018. [52000] The L-shaped tank shown in Fig. 15-32 is filled with water and is open at the top.

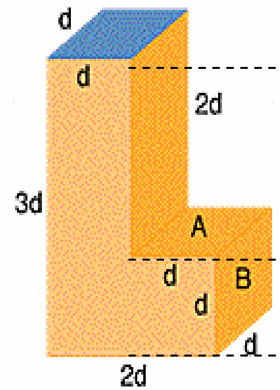


Figure 15-32

Pressure due to water:

$P_1 = 0$

$P_2 = \rho g(2d)$

$P_3 = \rho g(3d)$

$$P_{average} = \frac{P_2 + P_3}{2}$$

(a) If d = 5.5 m, what is the force on face *A* due to the water?

[0.133333] ______ N

(b) What is the force on face *B* due to the water?

[0.133333] ______ N

The wave equation:

velocity

$$\frac{\partial^2 y}{\partial t^2} = v^2 \frac{\partial^2 y}{\partial x^2}$$

where $v = \sqrt{\frac{T}{\mu}}$ (for a string)

$\sqrt{\frac{B}{\rho}} = \sqrt{\frac{\gamma P}{\rho}}$ (for gas (air))

Solutions: $y(x,t) = f(x \pm vt)$ ← function of *any* shape

Examples:

$$y(x,t) = y_0 e^{-(x-vt)^2}$$ pulse wave

$$y(x,t) = y_0 \sin(k(x-vt)+\varphi)$$ periodic wave

2. HRW6 17.P.014. [52087] The equation of a transverse wave on a string is

$$y = (2.0\text{ mm})\sin[(15\text{ m}^{-1})x - (550\text{ s}^{-1})t].$$

The tension in the string is 12 N.

(a) What is the wave speed?

[0.0714286] ______ m/s

(b) Find the linear density of this string in grams per meter.

[0.0714286] ______ g/m

$$y(x,t) = y_m \sin(k(x - vt)) = y_m \sin(kx - \omega t)$$

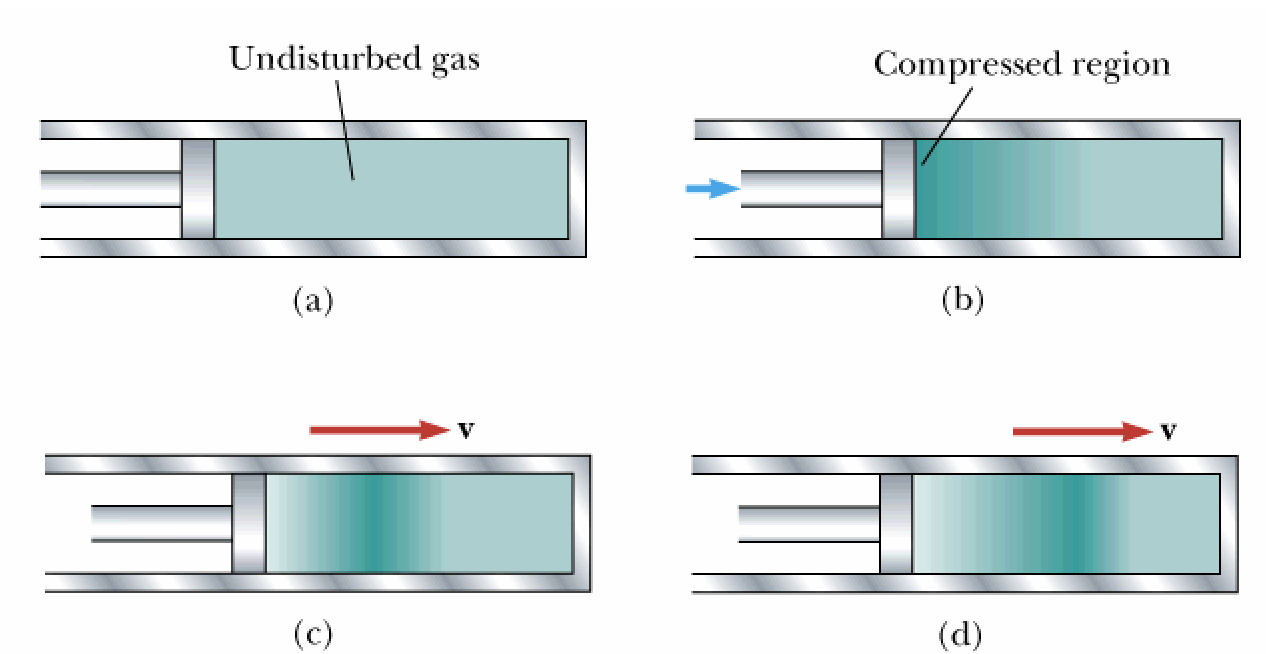
$$v = \frac{\omega}{k} = \sqrt{\frac{T}{\mu}}$$

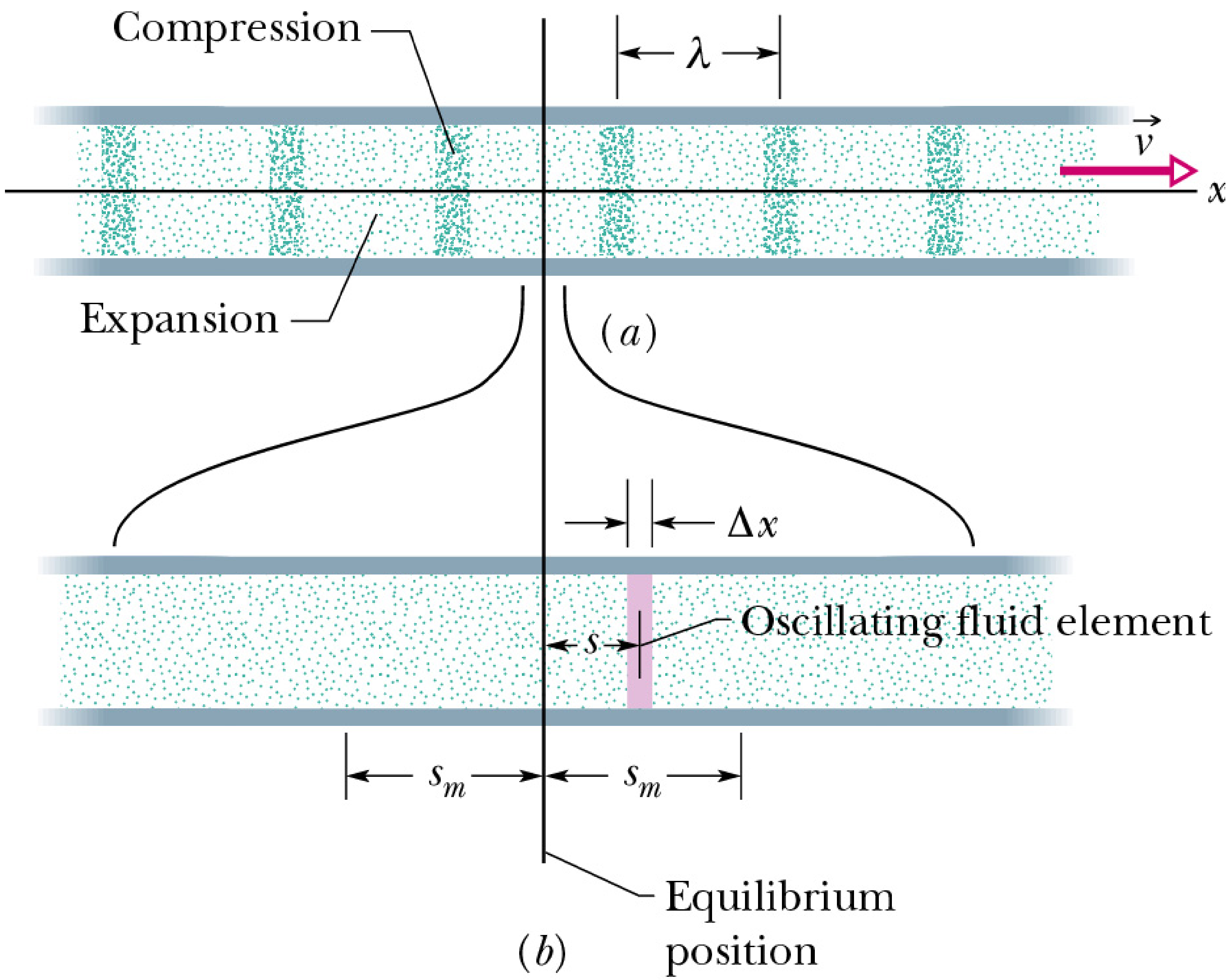
Sound waves

Longitudinal waves propagating in a fluid or solid

$$\frac{\partial^2 y}{\partial t^2} = v^2 \frac{\partial^2 y}{\partial x^2} \qquad y(x,t) \text{ describes density or pressure variations}$$

$$v = \sqrt{\frac{T}{\mu}} \Rightarrow \sqrt{\frac{B}{\rho}} \quad \left(\sqrt{\frac{\text{compressibility}}{\text{density}}}\right) = \sqrt{\frac{\gamma P}{\rho}} \approx 343 \text{ m/s}$$




Compression
λ
v
x
Expansion
(a)
Δx
Oscillating fluid element
s
s_m
s_m
Equilibrium position
(b)

Periodic sound wave

In terms of pressure:

$$P(x,t) = P_0 + \Delta P_{\max} \sin\left(\frac{2\pi x}{\lambda} \pm \frac{2\pi t}{T}\right)$$

Sound intensity: (energy/(unit time · unit area))

$$I \equiv \frac{(\Delta P_{\max})^2}{2\rho v}$$

Decibel scale:

$$\beta \equiv 10 \log\left(\frac{I}{I_0}\right) \qquad I_0 = 10^{-12}\ \mathrm{W/m^2}$$

Some representative values

Source	β (dB)
Lawn mower	100
Normal conversation	70
Mosquito buzzing	40
Threshold of hearing	0

Peer instruction question

Suppose that you are trying to sleep but your roommate has the stereo on at a sound level of β=100. In trying to diplomatically and accurately achieve an appropriate sound reduction, which of the following is better to request:

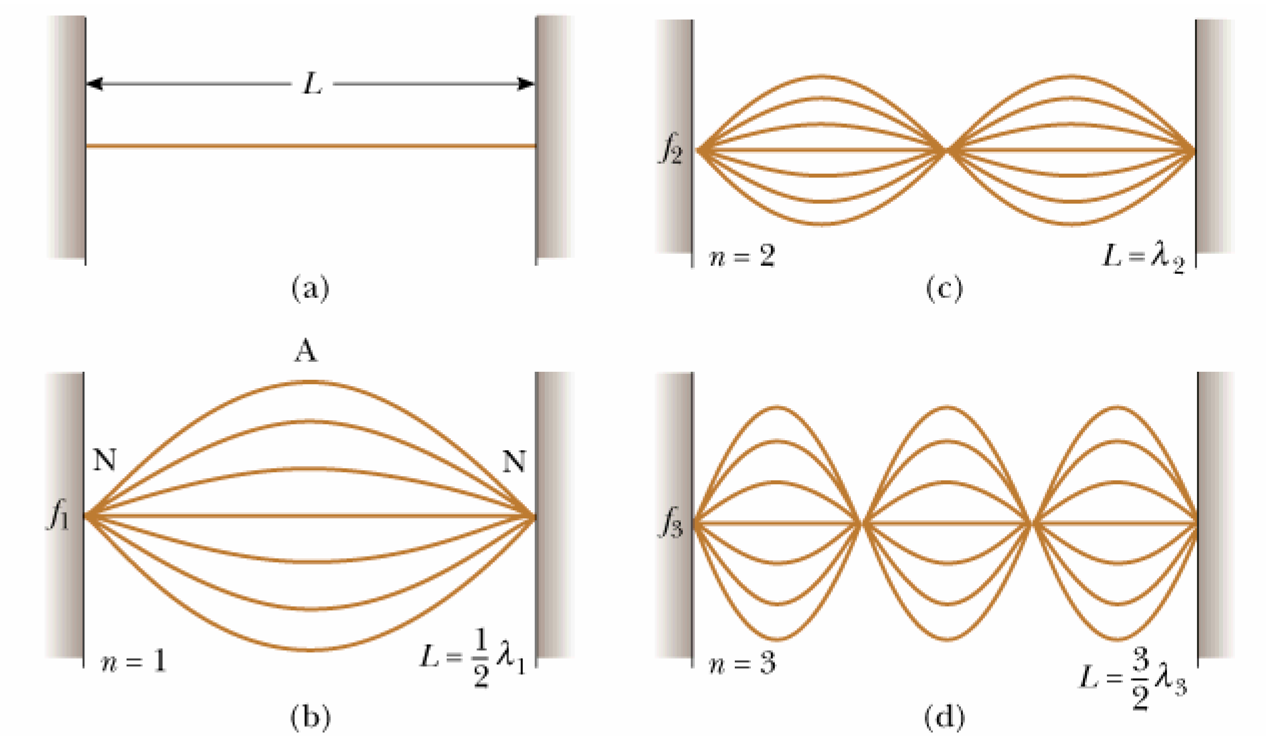
(A) Please reduce the stereo intensity by half.

(B) Please reduce the stereo decibel level by half.

(C) Please reduce the pressure amplitude of the sound wave produced by the stereo by half.

The sound of music

String instruments (Guitar, violin, etc.)



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

$$f_n = \frac{v}{\lambda_n} = \frac{nv}{2L}$$

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

(no sound yet.....) $y_{\text{standing}}(x,t) = 2y_0 \sin\left(\frac{2\pi x}{\lambda}\right)\cos\left(\frac{2\pi t}{T}\right)$

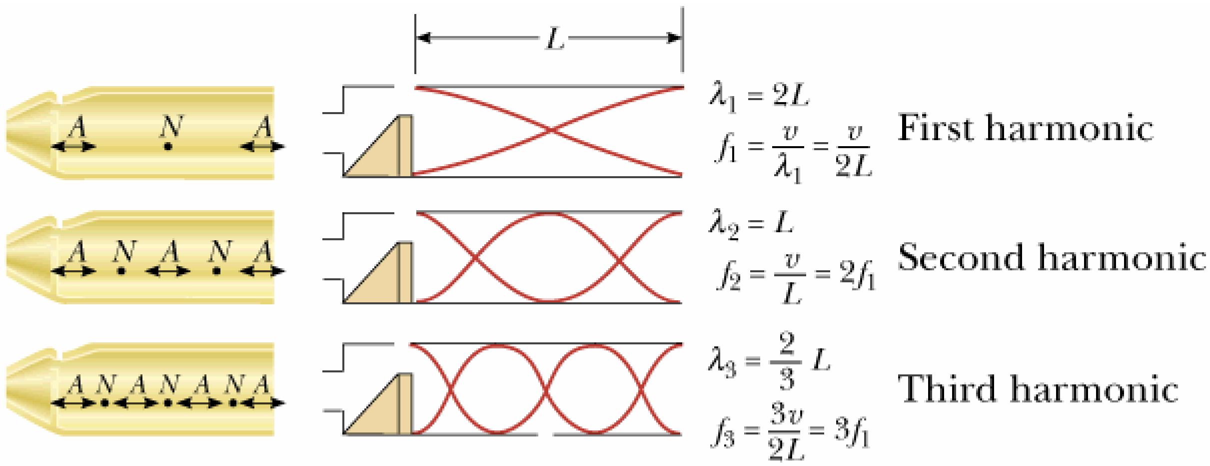
coupling to air

Peer instruction question

Suppose you pluck the “A” guitar string whose fundamental frequency is f=440 cycles/s. The string is 0.5 m long so the wavelength of the standing wave on the string is λ=1m. Assuming the speed of sound is 343 m/s, what is the wavelength of the sound wave which is produced?

(A) 1m (B) 0.78 m (C) 1.28 m

"Wind" instruments (standing waves in air)

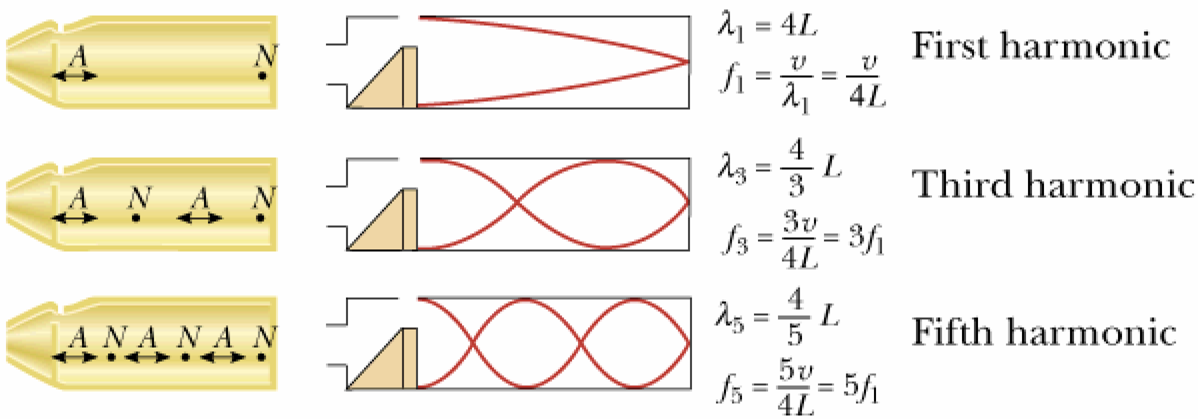


(a) Open at both ends

$$\lambda_n = \frac{2L}{n};\, n = 1,2,3,\ldots$$

$$f_n = \frac{v}{\lambda_n} = \frac{nv}{2L}$$

$$v = \sqrt{\frac{\gamma P}{\rho}} \approx 343 \text{ m/s}$$

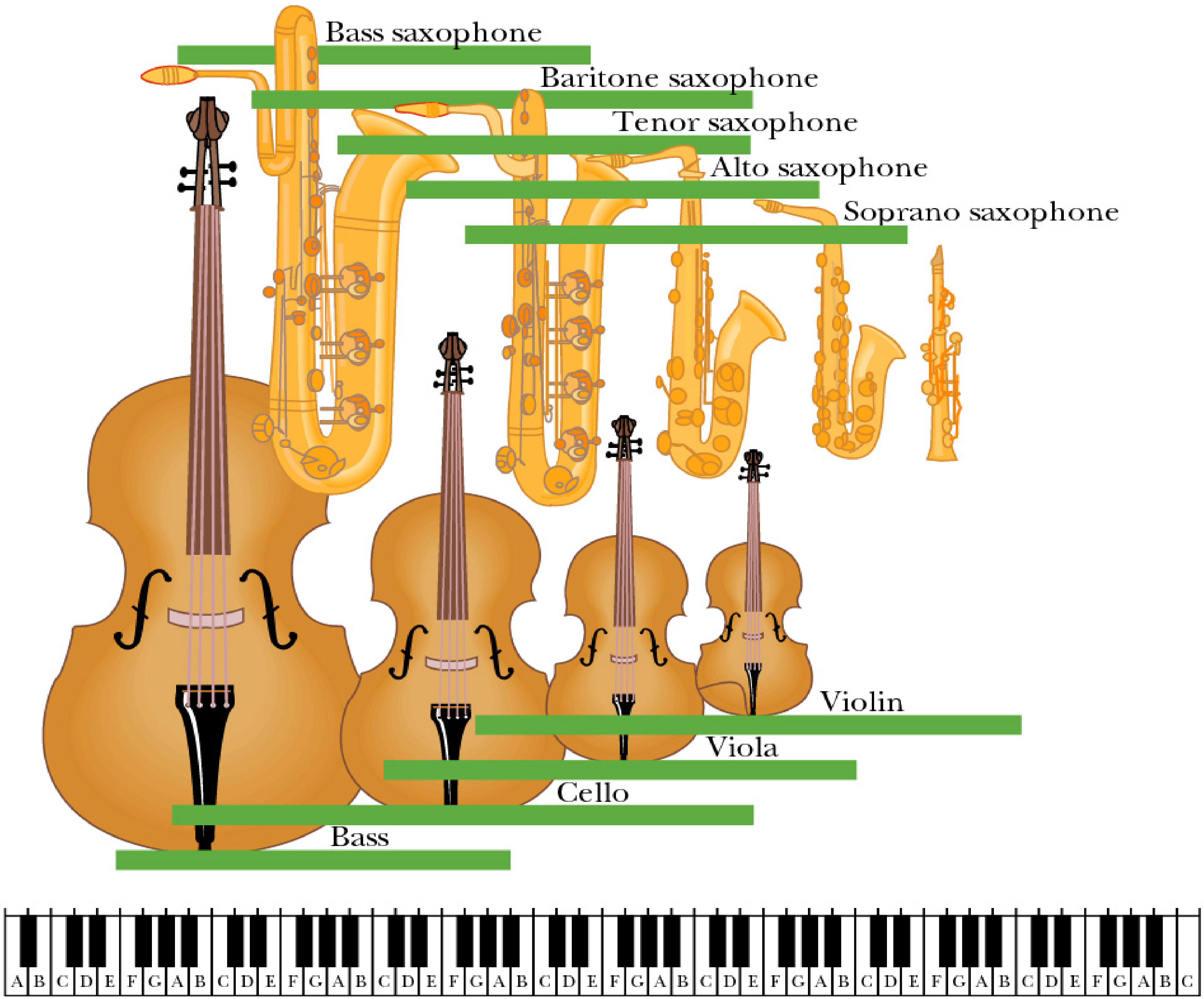


(b) Closed at one end, open at the other

$$\lambda_n = \frac{4L}{n};\, n = 1,3,5,\ldots$$

$$f_n = \frac{v}{\lambda_n} = \frac{nv}{4L}$$

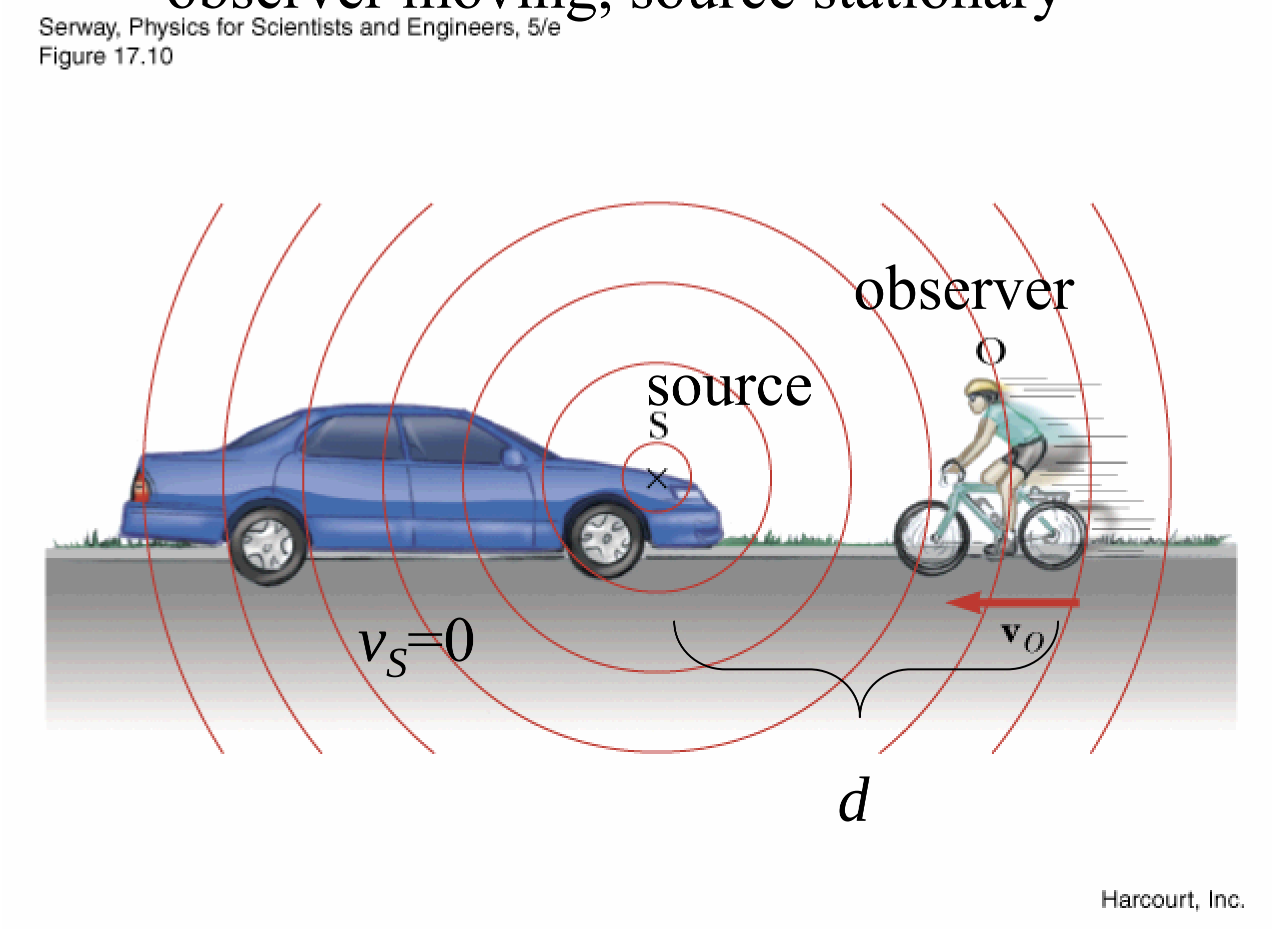
$$v = \sqrt{\frac{\gamma P}{\rho}} \approx 343 \text{ m/s}$$


Bass saxophone
Baritone saxophone
Tenor saxophone
Alto saxophone
Soprano saxophone
Violin
Viola
Cello
Bass
A B C D E F G A B C D E F G A B C D E F G A B C D E F G A B C D E F G A B C D E F G A B C D E F G A B C

The "Doppler" effect

v=sound velocity

observer moving, source stationary



$$vt_1 = d - v_O t_1$$

$$v(t_2 - T) = d - v_O t_2$$

$$t_2 - t_1 = \frac{1}{f_O} = T\frac{v}{v + v_O}$$

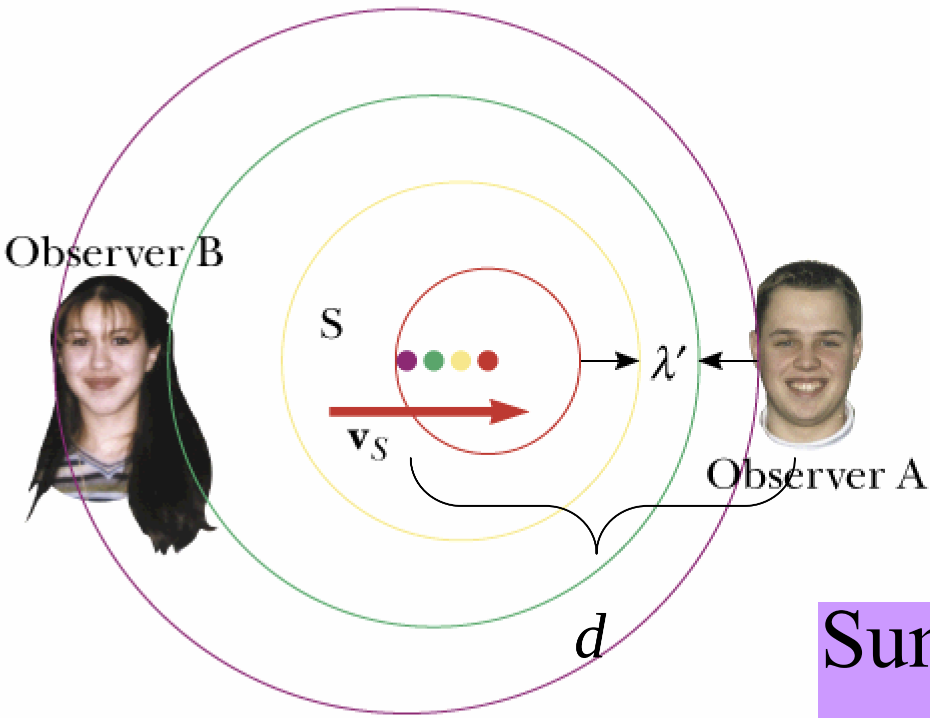
$$f_O = f_S \frac{v + v_O}{v}$$

The "Doppler" effect

v=sound velocity

observer stationary, source moving

Serway, Physics for Scientists and Engineers, 5/e
Figure 17.11a



(a)

$$vt_1 = d$$

$$v(t_2 - T) + v_S T = d$$

$$t_2 - t_1 = \frac{1}{f_O} = T\,\frac{v - v_S}{v}$$

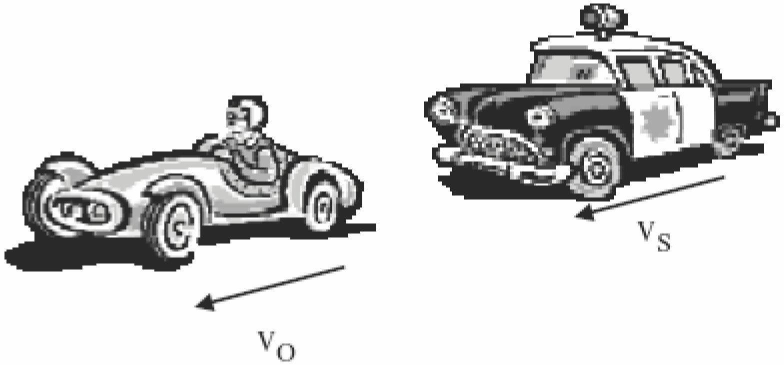
$$f_O = f_S \frac{v}{v - v_S}$$

Summary:

$$f_O = f_S \frac{v \pm v_O}{v \mp v_S}$$

toward

away



The figure on the left shows a car traveling at a velocity v_O being followed by a police car traveling at a velocity $v_S = 30$ m/s. The police car has a siren at frequency $f_S = 950$ cycles/s. The observer in the front car hears the siren at a frequency of $f_O = 920$ cycles/s.

(a) Is the front car moving faster or slower than the police car?

(b) What is the velocity of the front car v_O?

$$f_O = f_S \frac{v \pm v_O}{v \mp v_S}$$

toward

away

Velocity of sound:

$v = 343$ m/s

In this case :

$$f_O = f_S \frac{v - v_O}{v - v_S}$$

$$f_O < f_S \Rightarrow v_O > v_S$$

$$v_O = v - (v - v_S)\frac{f_O}{f_S} \approx 40\text{m/s}$$

Peer instruction question

Is Doppler radar described by the equations given above for sound Doppler?

(A) yes (B) no

Is "ultra sound" subject to the sound form of the Doppler effect?

(A) yes (B) no

Summary of sound Doppler effect:

$$f_O = f_S \frac{v \pm v_O}{v \mp v_S}$$

toward

away

Doppler effect for electromagnetic waves:

$$f_O = f_S \sqrt{\frac{v + v_R}{v - v_R}}$$

Relative velocity of source toward observer