Ondas II

Capítulo 17
Halliday, Resnick & Walker

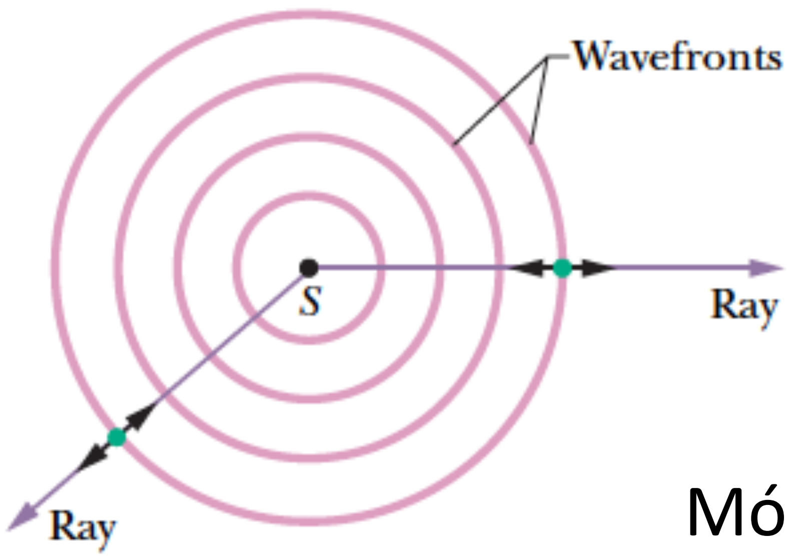
4300357 - Oscilações e Ondas

2° semestre de 2016

Onda Sonora

- Comum na natureza
- Aplicações em detecções e diagnósticos
- Onda longitudinal

A Velocidade do Som



$$v = \sqrt{\frac{\tau}{\mu}} = \sqrt{\frac{\text{elastic property}}{\text{inertial property}}}$$

Módulo de elasticidade volumétrica

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

Variações de P e V têm sinais opostos, B > 0

ρ : densidade de massa

Trocando τ por B, μ por ρ ➔

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

$\rho_{água} >> \rho_{ar}$

$B_{água} >> B_{ar}$

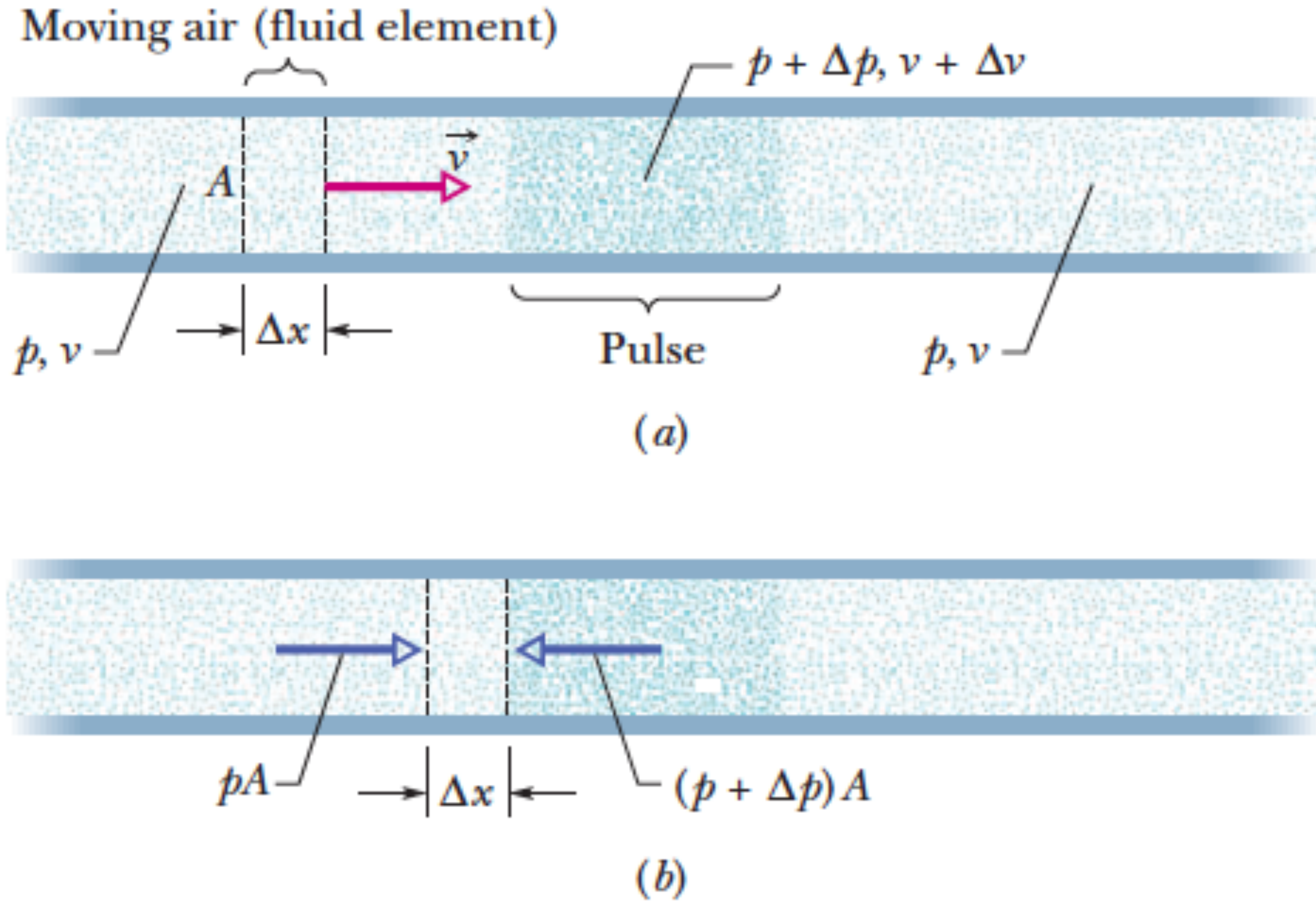
Água é pouco compressível

The Speed of Sound[a]

Medium	Speed (m/s)
Gases	
Air (0°C)	331
Air (20°C)	343
Helium	965
Hydrogen	1284
Liquids	
Water (0°C)	1402
Water (20°C)	1482
Seawater[b]	1522
Solids	
Aluminum	6420
Steel	5941
Granite	6000

[a] At 0°C and 1 atm pressure, except where noted.

[b] At 20°C and 3.5% salinity.



Referencial com pulso em repouso, ar se desloca

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

Tempo para volume de ar entrar no pulso

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

Força resultante

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

Massa do volume

|

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

Aceleração média

$$F = ma$$ ➔ $$-\Delta p\, A = (\rho A v\, \Delta t)\frac{\Delta v}{\Delta t}$$ ➔

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

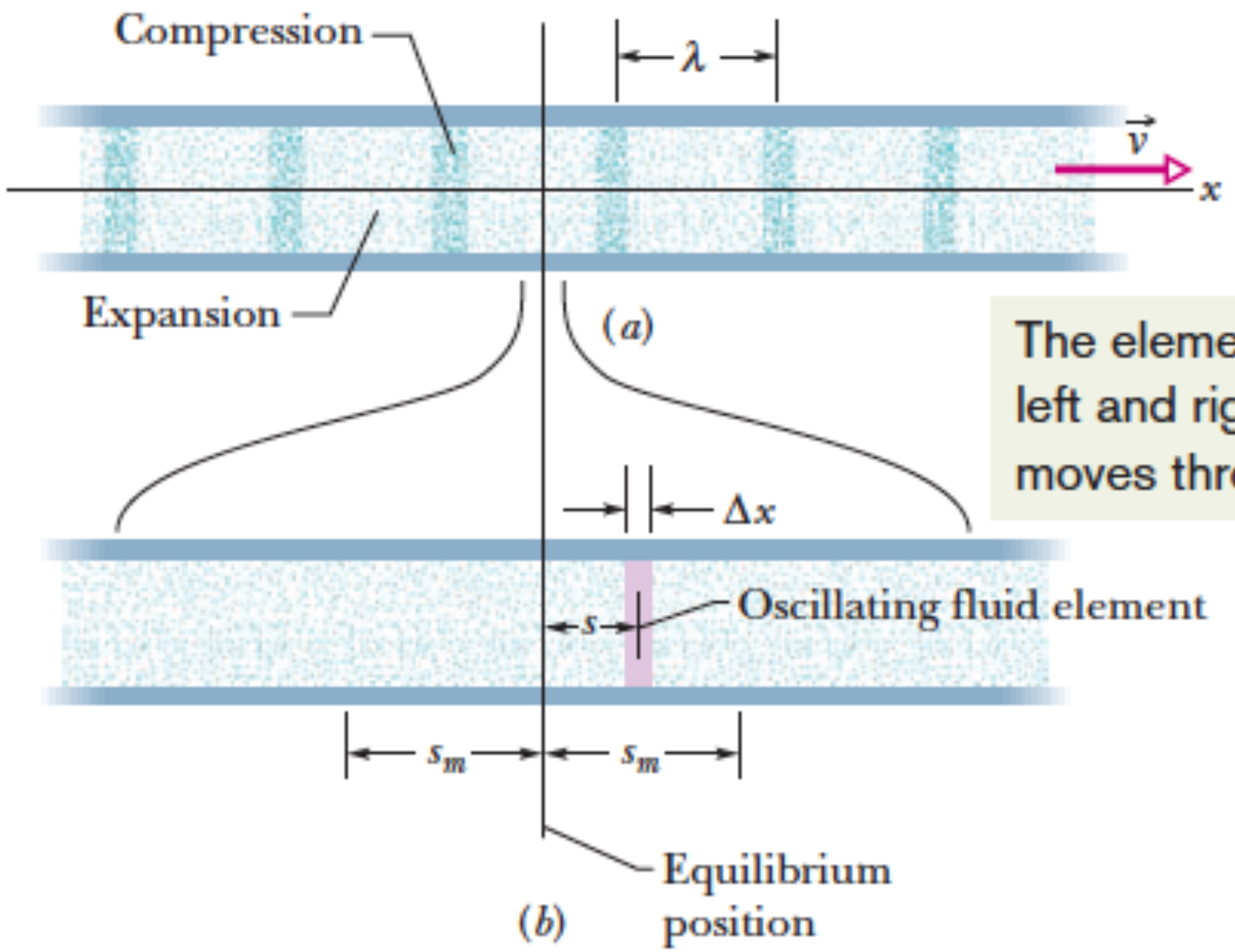
$$\frac{\Delta V}{V} = \frac{A\,\Delta v\,\Delta t}{A v\,\Delta t} = \frac{\Delta v}{v}.$$

Volume V varia ao entrar no pulso

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

Ondas Sonoras Progressivas

s_m : deslocamento do ar



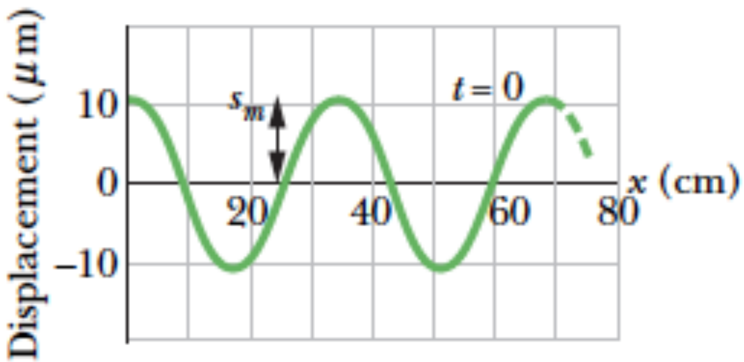
The element oscillates left and right as the wave moves through it.

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

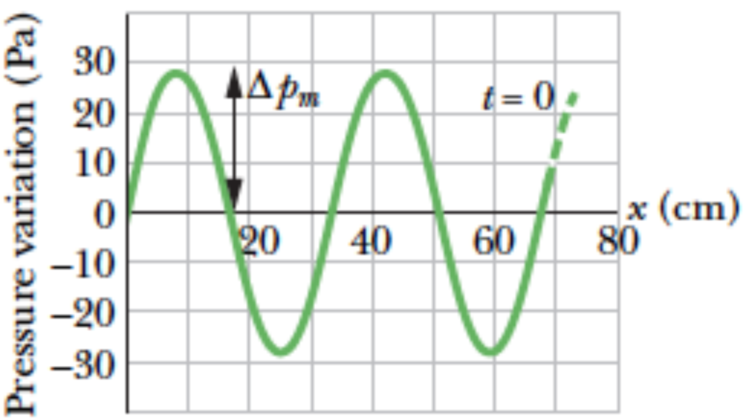
s_m : deslocamento do ar

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

Variação da pressão

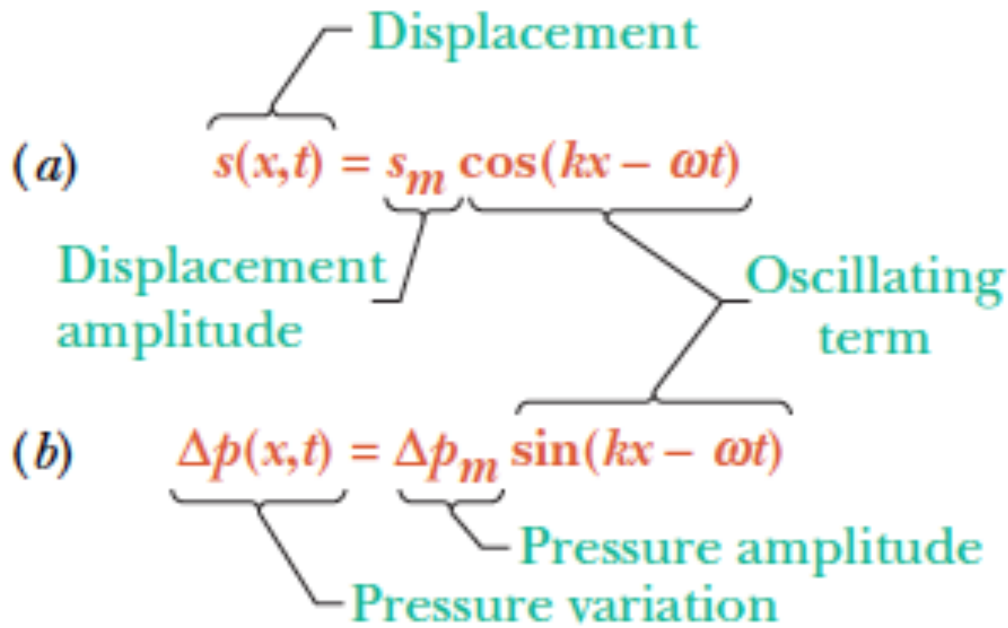


(a)



(b)

Onda sonora de 1000 Hz
No instante t = 0



Amplitude da oscilação da pressão

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

Interferência

Duas ondas de mesmo s_m, k, ω

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

$S_1 = s_m \cos(kx - \omega t)$

$S_2 = s_m \cos(kx - \omega t + \phi)$

$S = S_1 + S_2$

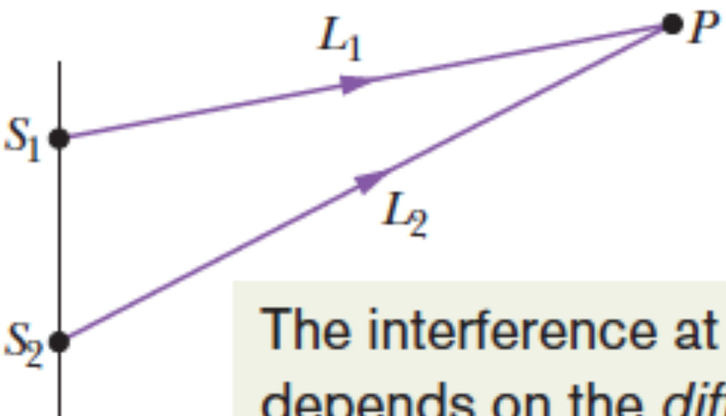
Onda resultante

$S = [2 s_m \cos \phi/2] \cos(kx - \omega t + \phi/2)$

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

Diferença de percurso ΔL

Duas ondas esféricas atingem ponto P



The interference at *P* depends on the *difference* in the path lengths to reach *P*.

If the difference is equal to, say, 2.0λ, then the waves arrive exactly in phase. This is how transverse waves would look.

If the difference is equal to, say, 2.5λ, then the waves arrive exactly out of phase. This is how transverse waves would look.

Interferência construtiva

$$\phi = m(2\pi), \qquad \text{for } m = 0, 1, 2, \ldots \rightarrow \frac{\Delta L}{\lambda} = 0, 1, 2, \ldots$$

Interferência destrutiva

$$\phi = (2m + 1)\pi, \qquad \text{for } m = 0, 1, 2, \ldots \rightarrow \frac{\Delta L}{\lambda} = 0.5, 1.5, 2.5, \ldots$$

Intensidade e Nível Sonoro

Intensidade
(Potência / área)

$$I = \frac{P}{A}$$

$$I = \tfrac{1}{2}\rho v \omega^2 s_m^2.$$

Para uma fonte pontual isotrópica

$$I = \frac{P_s}{4\pi r^2},$$

A Escala de Decibéis

No ouvido humano, as intensidades variam de um fator até 10^{12}

$$y = \log x$$

$$y' = \log(10x) = \log 10 + \log x = 1 + y$$

Nível sonoro (dB)

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

$I_o = 10^{-12}$ W/m^2 ➔ $\beta = 0$

Para $I = 10^4 I_o$ ➔ $\beta = 40$ dB

Recently, many rockers, such as Lars Ulrich of Metallica (Fig. 17-11), began wearing special earplugs to protect their hearing during performances. If an earplug decreases the sound level of the sound waves by 20 dB, what is the ratio of the final intensity I_f of the waves to their initial intensity I_i?

Calculations: For the final waves we have

$$\beta_f = (10 \text{ dB}) \log \frac{I_f}{I_0},$$

and for the initial waves we have

$$\beta_i = (10 \text{ dB}) \log \frac{I_i}{I_0}.$$

The difference in the sound levels is

$$\beta_f - \beta_i = (10 \text{ dB}) \left(\log \frac{I_f}{I_0} - \log \frac{I_i}{I_0} \right).$$

Using the identity

$$\log \frac{a}{b} - \log \frac{c}{d} = \log \frac{ad}{bc},$$

we can rewrite Eq. 17-36 as

$$\beta_f - \beta_i = (10 \text{ dB}) \log \frac{I_f}{I_i}.$$

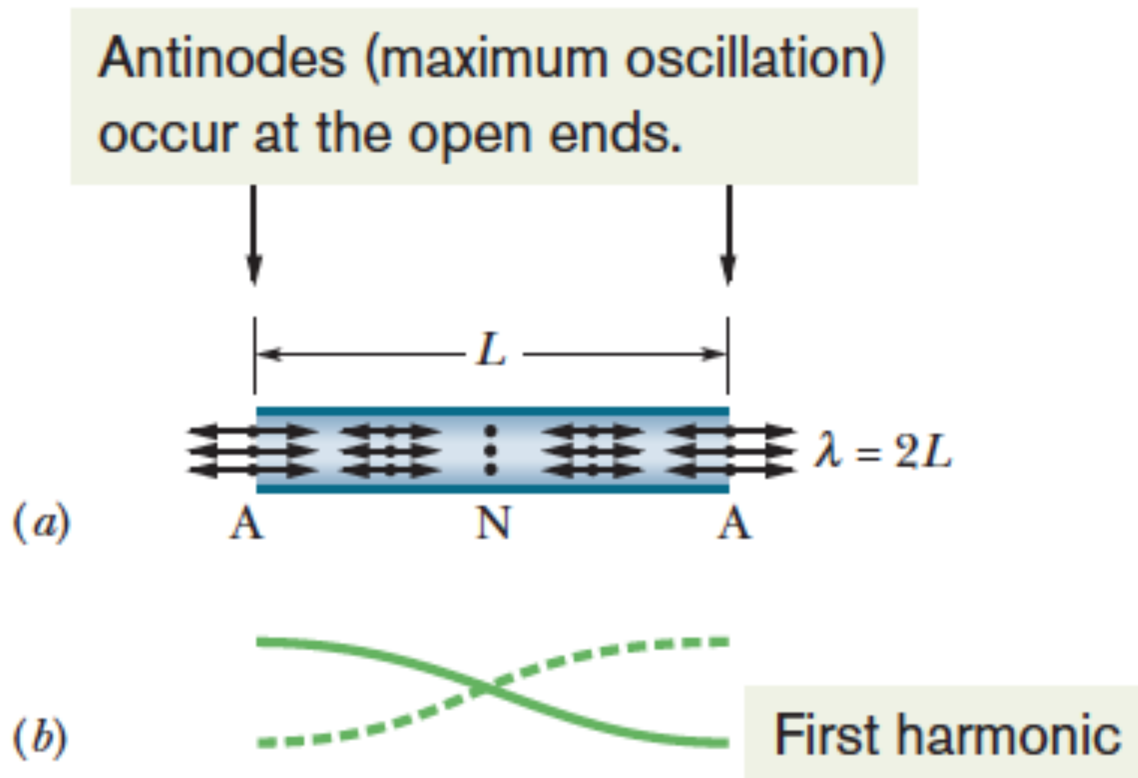
$$\beta_f - \beta_i = -20\ \text{dB} \quad \rightarrow$$

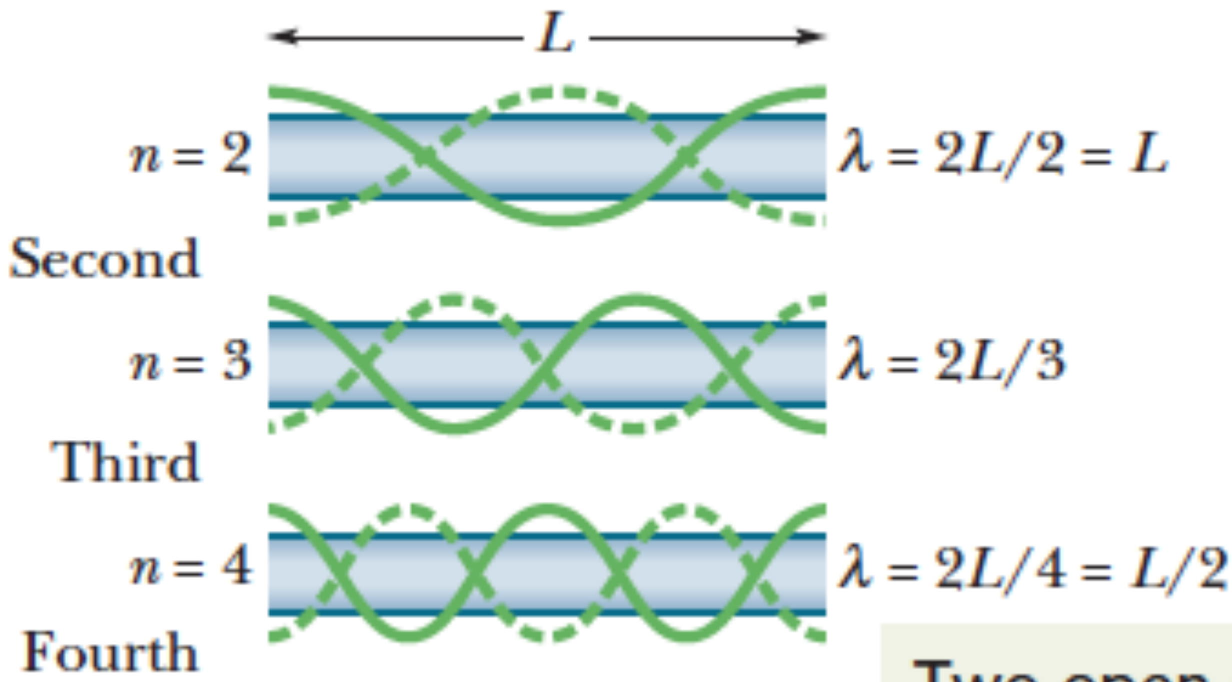
$$\log \frac{I_f}{I_i} = \frac{\beta_f - \beta_i}{10\ \text{dB}} = \frac{-20\ \text{dB}}{10\ \text{dB}} = -2.0$$

$$\frac{I_f}{I_i} = \log^{-1}(-2.0) = 0.010$$

I diminui duas ordens de magnitude

Fontes de Sons Musicais



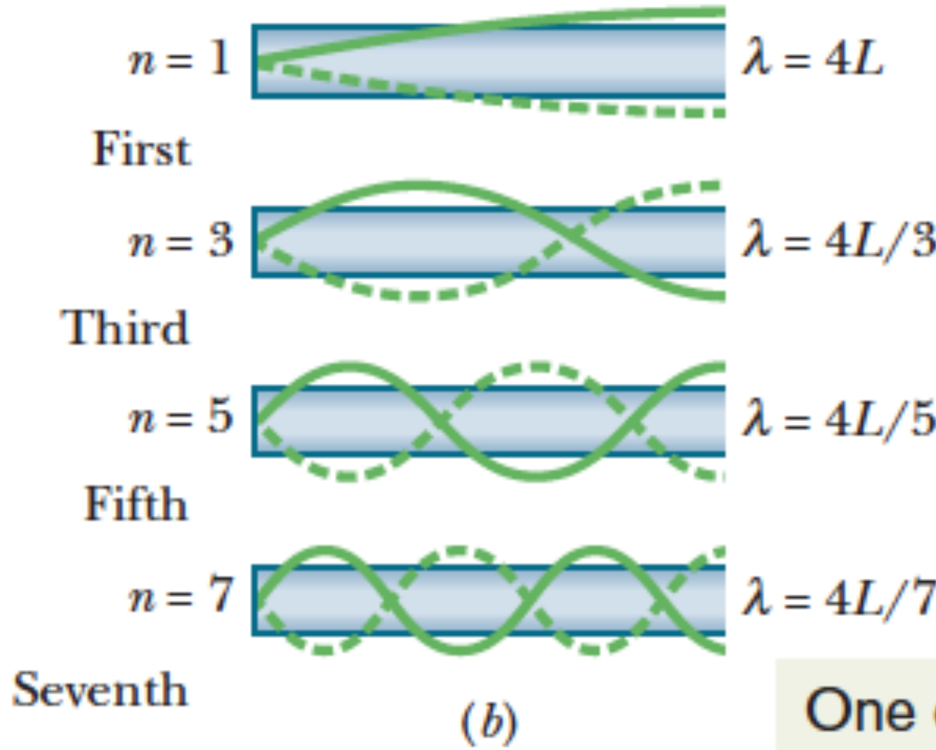


(a)

Two open ends—
any harmonic

$$\lambda = \frac{2L}{n}, \quad \text{for } n = 1, 2, 3, \ldots$$

$$f = \frac{v}{\lambda} = \frac{nv}{4L}, \quad \text{for } n = 1, 3, 5, \ldots$$



(b)

One open end—
only *odd* harmonics

$$\lambda = \frac{4L}{n}, \qquad \text{for } n = 1, 3, 5, \ldots$$

$$f = \frac{v}{\lambda} = \frac{nv}{4L}, \qquad \text{for } n = 1, 3, 5, \ldots \qquad \text{(pipe, one open end).}$$

Batimento

Let the time-dependent variations of the displacements due to two sound waves of equal amplitude s_m be

$$s_1 = s_m \cos \omega_1 t \qquad \text{and} \qquad s_2 = s_m \cos \omega_2 t, \tag{17-42}$$

where $\omega_1 > \omega_2$. From the superposition principle, the resultant displacement is

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

Using the trigonometric identity (see Appendix E)

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

allows us to write the resultant displacement as

$$s = 2s_m \cos[\tfrac{1}{2}(\omega_1 - \omega_2)t] \cos[\tfrac{1}{2}(\omega_1 + \omega_2)t]. \tag{17-43}$$

If we write

$$\omega' = \tfrac{1}{2}(\omega_1 - \omega_2) \qquad \text{and} \qquad \omega = \tfrac{1}{2}(\omega_1 + \omega_2), \tag{17-44}$$

we can then write Eq. 17-43 as

$$s(t) = [2s_m \cos \omega' t] \cos \omega t. \tag{17-45}$$

$$s(t) = [2s_m \cos \omega' t] \cos \omega t.$$

$$\omega' = \tfrac{1}{2}(\omega_1 - \omega_2) \quad \text{and} \quad \omega = \tfrac{1}{2}(\omega_1 + \omega_2).$$

Frequências próximas $\omega_1 \cong \omega_2$ ➔ $\omega >> \omega'$

Duas oscilações com amplitude máxima a cada período

$$\omega_{\text{beat}} = 2\omega' = (2)(\tfrac{1}{2})(\omega_1 - \omega_2) = \omega_1 - \omega_2.$$

Batimento

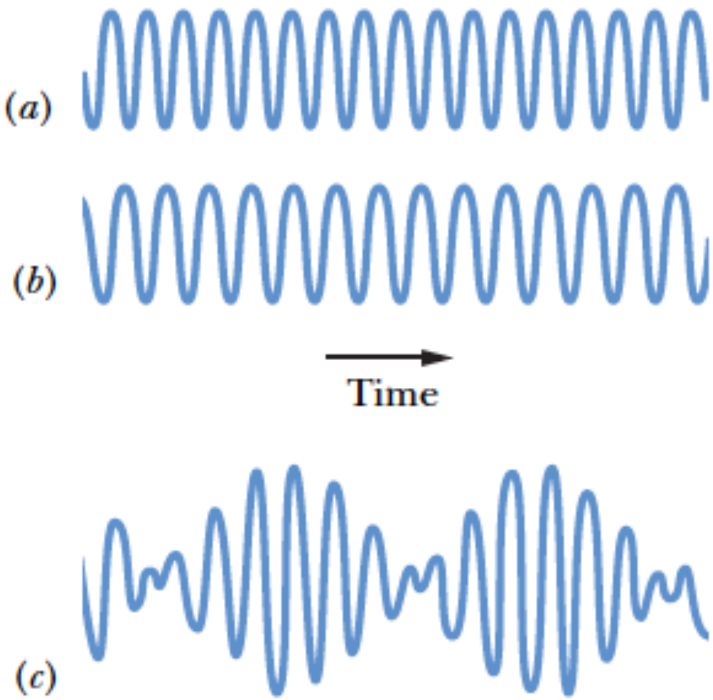


Fig. 17-17 (*a*, *b*) The pressure variatioı Δp of two sound waves as they would be detected separately. The frequencies of thı waves are nearly equal. (*c*) The resultant pressure variation if the two waves are detected simultaneously.

Efeito Dopller

$$f' = f\frac{v \pm v_D}{v \pm v_S}$$

f': freqência detectada

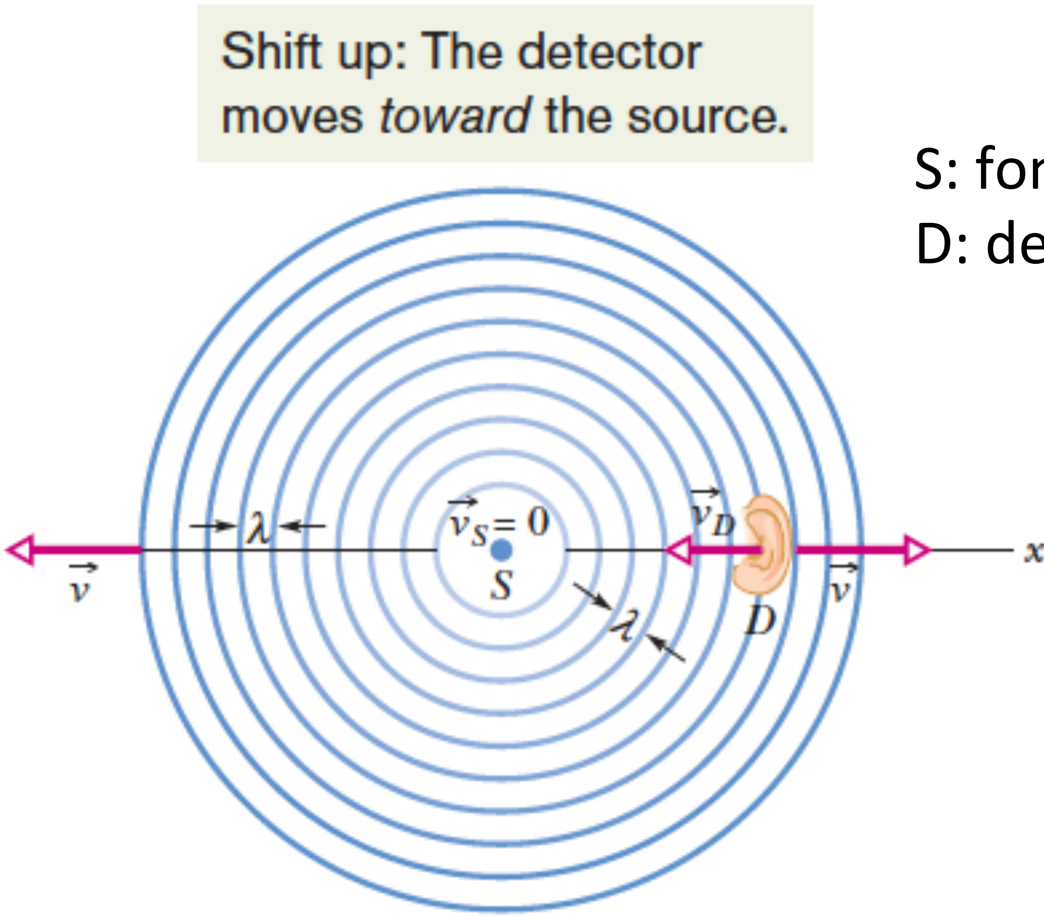
f: frequência emitida

v : velocidade do som no ar

v_d: velocidade do detector em relação ao ar

v_s: velocidade da fonte em relação ao ar

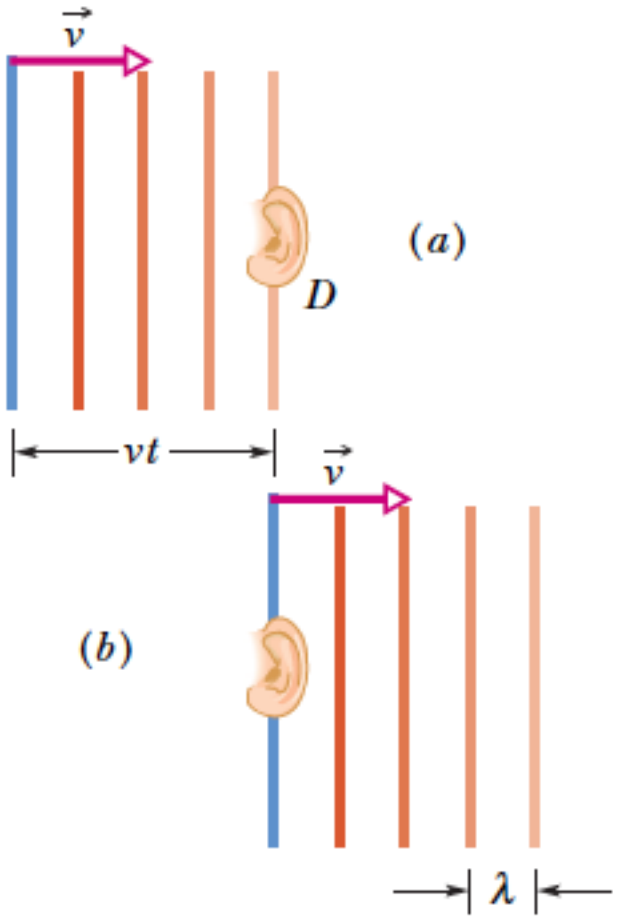
Detetor em Movimento, Fonte Parada



S: fonte esférica
D: detector

Se v_d = 0, a frequência detectada é a emitida

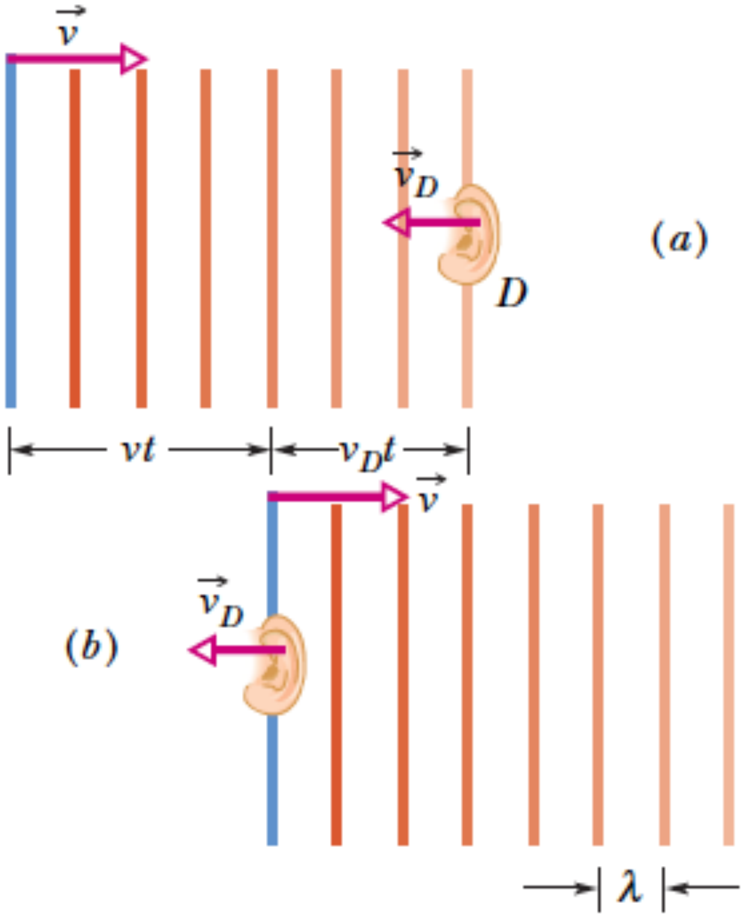
Detetor e Fonte Parados



$$f = \frac{vt/\lambda}{t} = \frac{v}{\lambda}$$

Se $v_d = 0$, a frequência detectada é a emitida

Detetor em Movimento, Fonte Parada



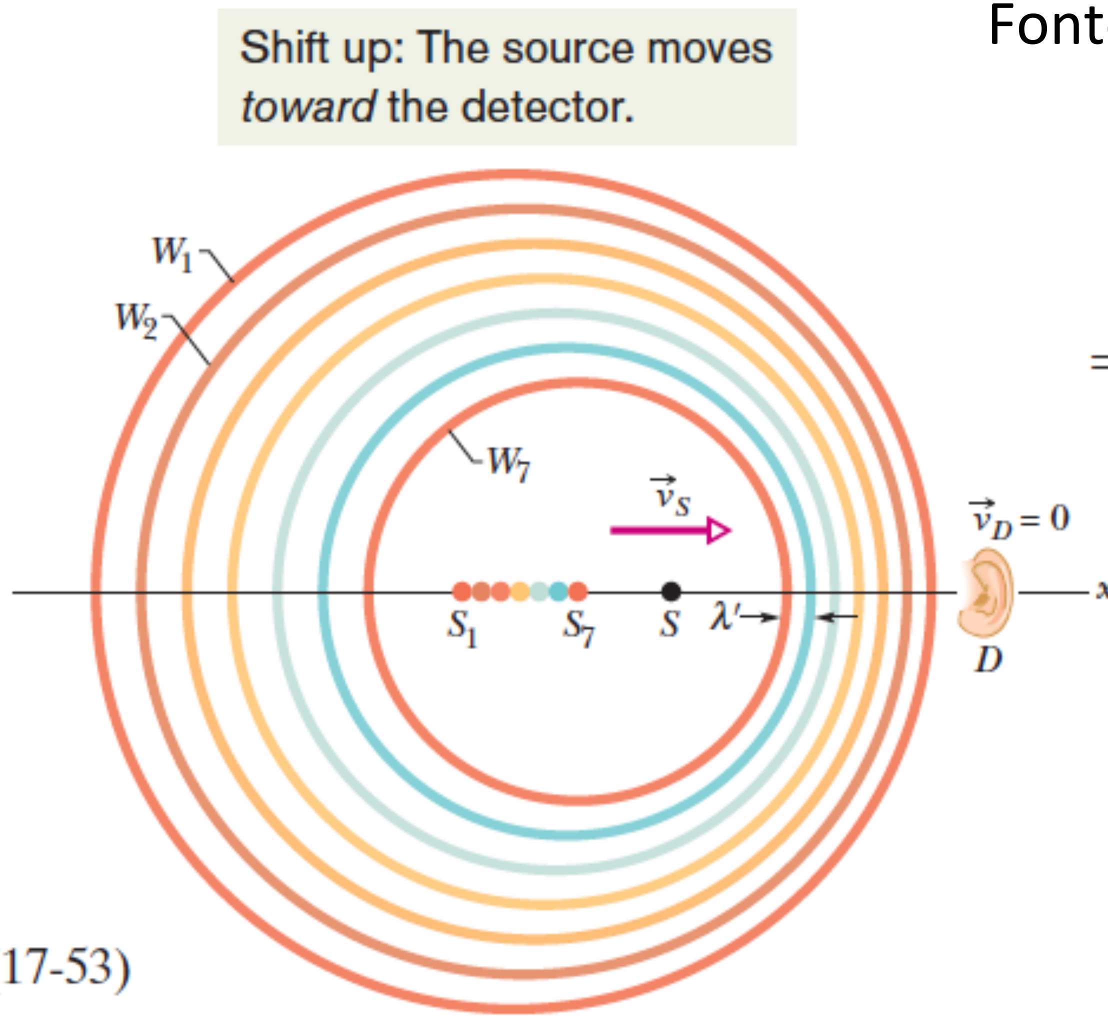
Detetor se aproxima da fonte

$$f' = \frac{(vt + v_D t)/\lambda}{t} = \frac{v + v_D}{\lambda}$$

$$f' = \frac{v + v_D}{v/f} = f\frac{v + v_D}{v}$$

Detetor em movimento $$f' = f\frac{v \pm v_D}{v}$$

Fonte em Movimento, Detetor Parado



Fonte se aproxima do detetor

$$f' = \frac{v}{\lambda'} = \frac{v}{vT - v_S T}$$

$$= \frac{v}{v/f - v_S/f} = f\frac{v}{v - v_S}$$

(17-53)

Fonte em movimento

$$f' = f\frac{v}{v \pm v_S}$$