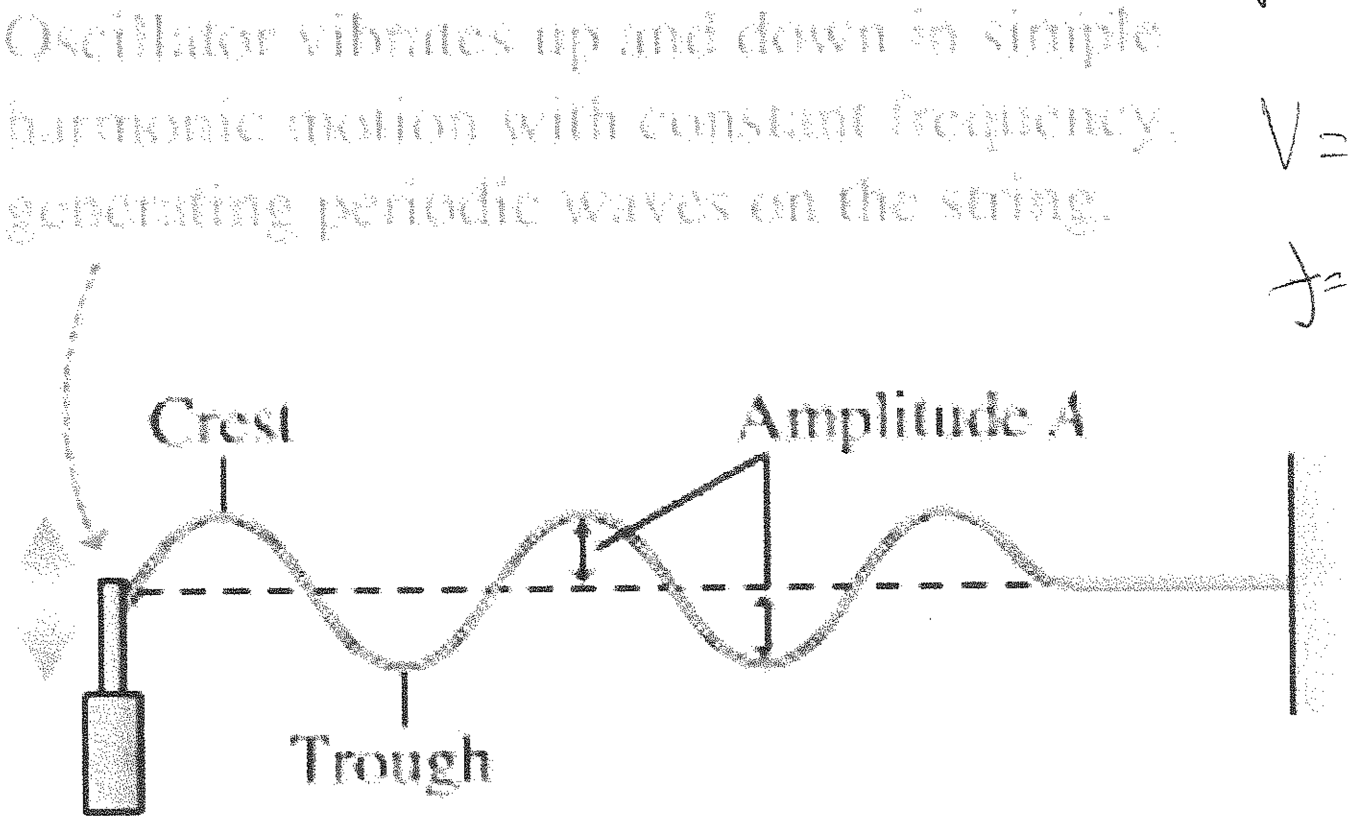
Lecture 39

(CH11:4-5)

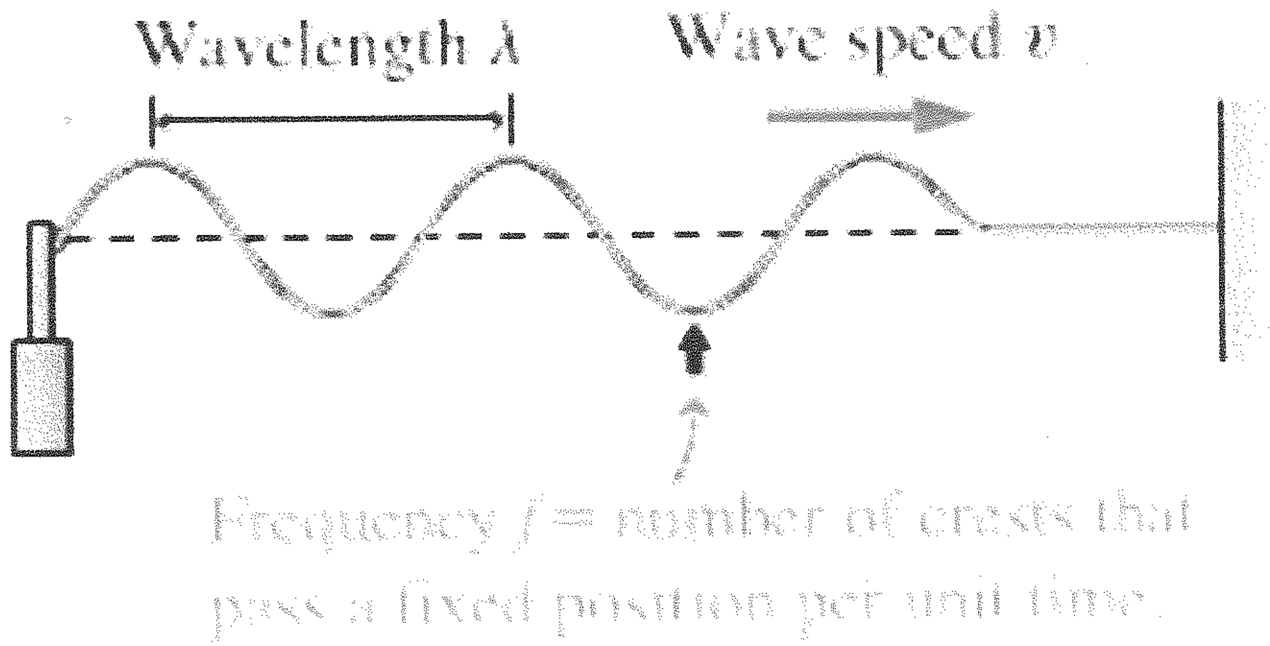
$V = \lambda . f$

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

$f = \frac{1}{T}$ [Hz]



(a) Generating periodic waves on a string



(b) Wavelength, wave speed, and frequency

Bacon   Radio FM = 98.1 MHz; $C = 3 * 10^8 \frac{m}{s}$

$\lambda = ?$

18. ORGANIZE AND PLAN We are given the frequency f and the velocity c.

The fundamental relationship is:

$\lambda = V \cdot T \rightarrow V = \frac{\lambda}{T} = \lambda \cdot f$

$$v = \lambda f$$

Solving for *lambda*: $\lambda = \frac{v}{f}$

Additional notes: Frequency is given in units of $\text{MHz} = 10^6\ \text{Hz}$

SOLVE Plugging in values:

$$\lambda = \frac{3.0 \times 10^8\ \text{m/s}}{98.1 \times 10^6\ \text{Hz}} = 3.1\ \text{m}$$

REFLECT Another straightforward application of the fundamental relationship with a slight wrinkle of units. We learn that the wavelength of an FM radio station is around 3 meters. This wavelength gives an idea of the size of objects that the waves can diffract (or "bend") around and why you cannot receive FM radio under a bridge.

Book $\lambda_{sound} = ?$ if $f = 50$ kHz, $V_{air} = 343 \frac{m}{s}$

46. **ORGANIZE AND PLAN** We are given the frequency, we know the speed of sound at 20°, and we are asked to find the wavelength. The fundamental relationship is $\lambda = v/f$.

//

SOLVE Plugging in values:

The wavelength associated with the highest frequency a dog can hear is

$V = \frac{\lambda}{T} = \lambda f$

$\frac{V}{f} = \lambda$

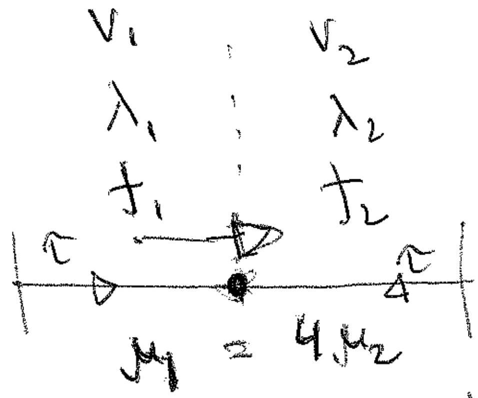
$$\lambda = \frac{343 \text{ m/s}}{50 \times 10^3 \text{ Hz}} = 6.86 \times 10^{-3} \text{ m} = 6.86 \text{ mm}$$

REFLECT

The shortest wavelength humans can hear, roughly 17 mm corresponds to 20 kHz. The wavelength determines the length scale of objects around which sound can diffract. Such considerations aid in developing theories of sound localization and mechanisms for hearing.

36. A long string is constructed by joining the ends of 2 shorter strings. The tension in the strings is the same but string I has 4 times the linear density of string II. When a sinusoidal wave passes from string I to string II:

1) the frequency decreases by a factor of 4
2) the frequency decreases by a factor of 2
3) the wavelength decreases by a factor of 4
4) the wavelength decreases by a factor of 2
5) the wavelength increases by a factor of 2



$V = \sqrt{\frac{\tau}{\mu}}$, where $\mu_i = \frac{M_i}{L_i}$; $i = 1, 2$

Power $\quad I = \frac{P}{\text{Area}} \approx \frac{P}{4\pi r^2} \approx \frac{P}{r^2}$ $\quad$ so if $r \to 2r$ $\quad I_{2r} \to \frac{P}{(2r)^2} \to \frac{I_r}{4}$

at $r = 25$ m : $\beta = 55$ dB

50. **Organize and Plan** We shall treat the sound source as a point source in open space. The sound intensity is inversely proportional to the distance squared. $I_1 = P_1/(d_1)^2$ where P_1 is a property of the source only and $d_1 = 25$ m. The intensity at $d = 50$ m is $I_2 = \frac{I_1}{4}$ while the intensity at $d = 250$ m is $I_2 = \frac{I_1}{100}$.
The sound intensity level is defined to be

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

Manipulating the SIL into a form more appropriate for the given information we note:

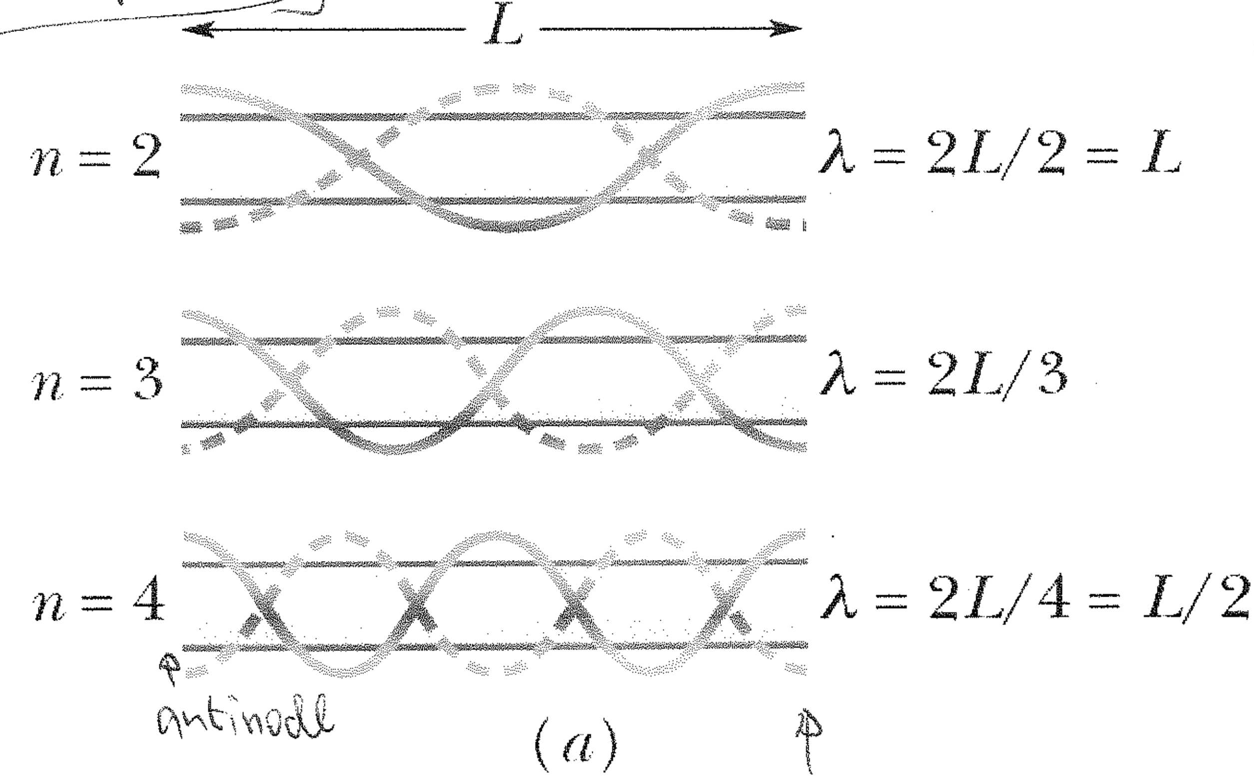
$$SIL = 10\ \log\frac{I_1}{\gamma I_o} = 10\ \log\frac{I_1}{I_o} - 10\ \log\gamma$$

We are given $55\ \text{dB} = 10\ \log\frac{I_1}{I_o}$ so the SIL for this problem is:

$$SIL = 55\ \text{dB} - 10\ \log\gamma$$

Solve Part (a): The SIL for $d = 50$ m (corresponding to $\gamma = 4$) is: 49 dB
Part (b): The SIL for $d = 250$ m (corresponding to $\gamma = 100$) is: 35 dB

Two open ends



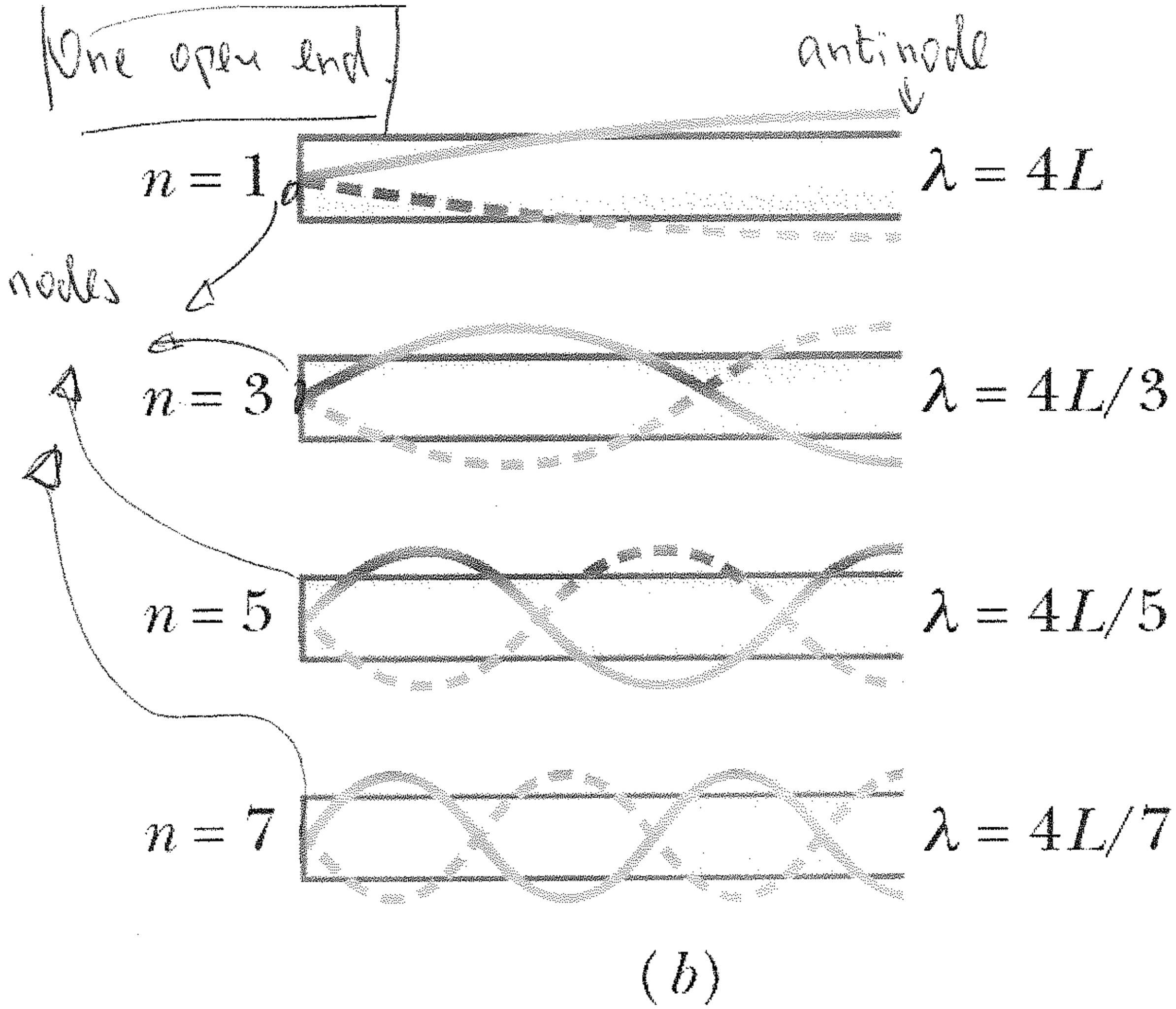
$\lambda = \frac{2L}{n}$

since $f = \frac{v}{\lambda}$

$f = \frac{nv}{2L}$

$n = 1, 2, 3 \ldots$

One open end



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

$f = \frac{nV}{4L}$

$n = 1, 3, 5, 7$

odd numbers

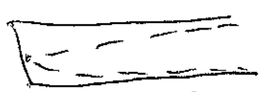
43. A 200 cm open organ with one end open pipe is in resonance with a sound wave of wavelength 270 cm. The pipe is operating in its:

1) fundamental frequency
2) first overtone
3) second overtone
4) third overtone
5) fourth overtone

$L = 2m$ | $f = ?$

$\lambda = 2.7m$

$L = 2m$



$\lambda = 2.7m$

$f = \frac{nV}{4L}$; $\lambda = \frac{4L}{n}$ | $n = 1, 3, 5 \ldots$

Ans: 2

$\frac{4L}{\lambda} = n = \frac{4 * 2}{2.7} \approx 3$

$n = 1$ fundamental

$n = 3$ first

$2.16\,m = \lambda = \frac{2L}{n}$; $f = n\frac{V}{2L}$, $n = 1, 2, 3, 4 \ldots$

66. ORGANIZE AND PLAN With a fundamental wavelength of λ_o, the frequency is $f_o = v/\lambda_o$. The second harmonic has twice the frequency and half the wavelength. The distance between nodes for the second harmonic is 1/2 the distance between nodes of the fundamental, which is $\lambda_o/2$. Therefore the distance between nodes in the second harmonic is $\lambda_o/4$.

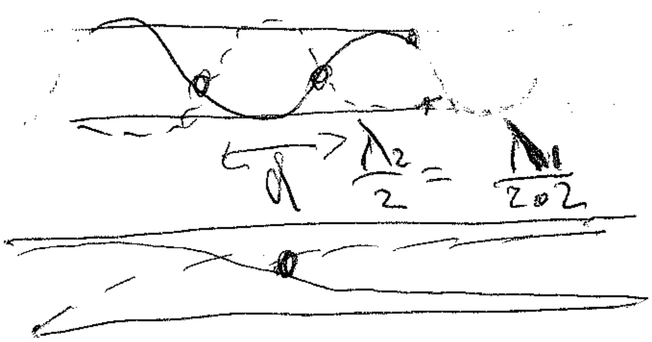
SOLVE The fundamental frequency is $f_o = 343\text{ m/s}/2.16\text{ m} = 159\text{ Hz}$
The distance between nodes for the second harmonic is $2.16\text{ m}/4 = 0.54\text{ m}$
REFLECT The fundamental frequency of this pipe corresponds to a flat E or sharp E flat. You could place a small hole in the pipe (like a register hole in a flute) at the node of the second harmonic and diminish the fundamentals contribution to the tone but not affect the second harmonic.

$V = \frac{\lambda}{T} = \lambda f \Rightarrow f = \frac{V}{\lambda}$

$f = \frac{343\,m/s}{2.16\,m} = 158\text{ Hz}$

Also $\lambda_1 = \frac{2L}{1} \to L = \frac{\lambda_1}{2} = 1.08\,m$; $\lambda_1 = 2.16\,m$

$\lambda_2 = \frac{2L}{2} = \frac{2 * \lambda_1}{2 * 2} = \frac{\lambda_1}{2} = 1.08\,m$



$\lambda_2 = L$, $n = 2$

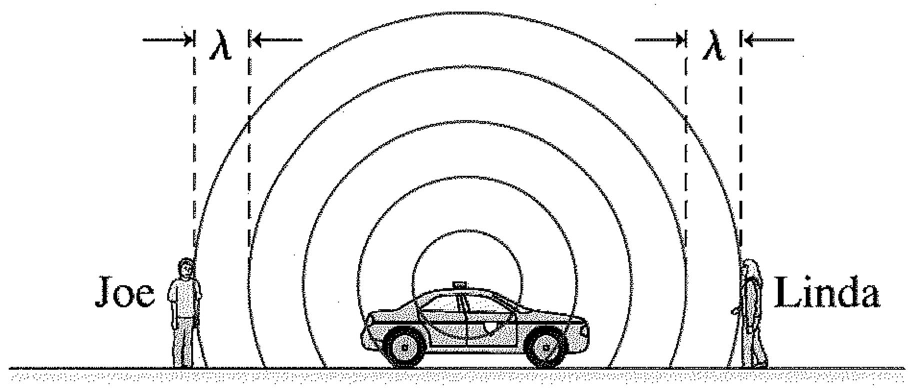
$\lambda_1 = 2L$, $n = 1$

$d = \frac{\lambda_1}{4} = 0.54\,m$

Doppler Effect

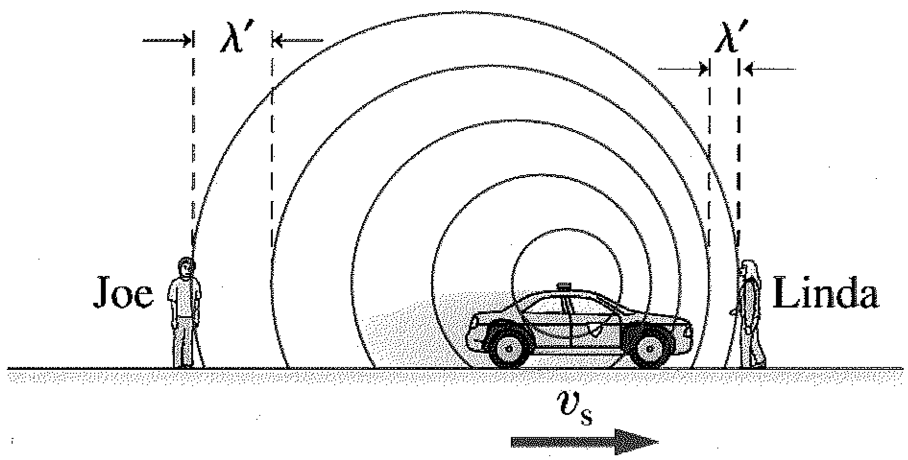
Figure 11.17

When source is stationary, wavelength and frequency are the same for both listeners.



(a) Stationary source

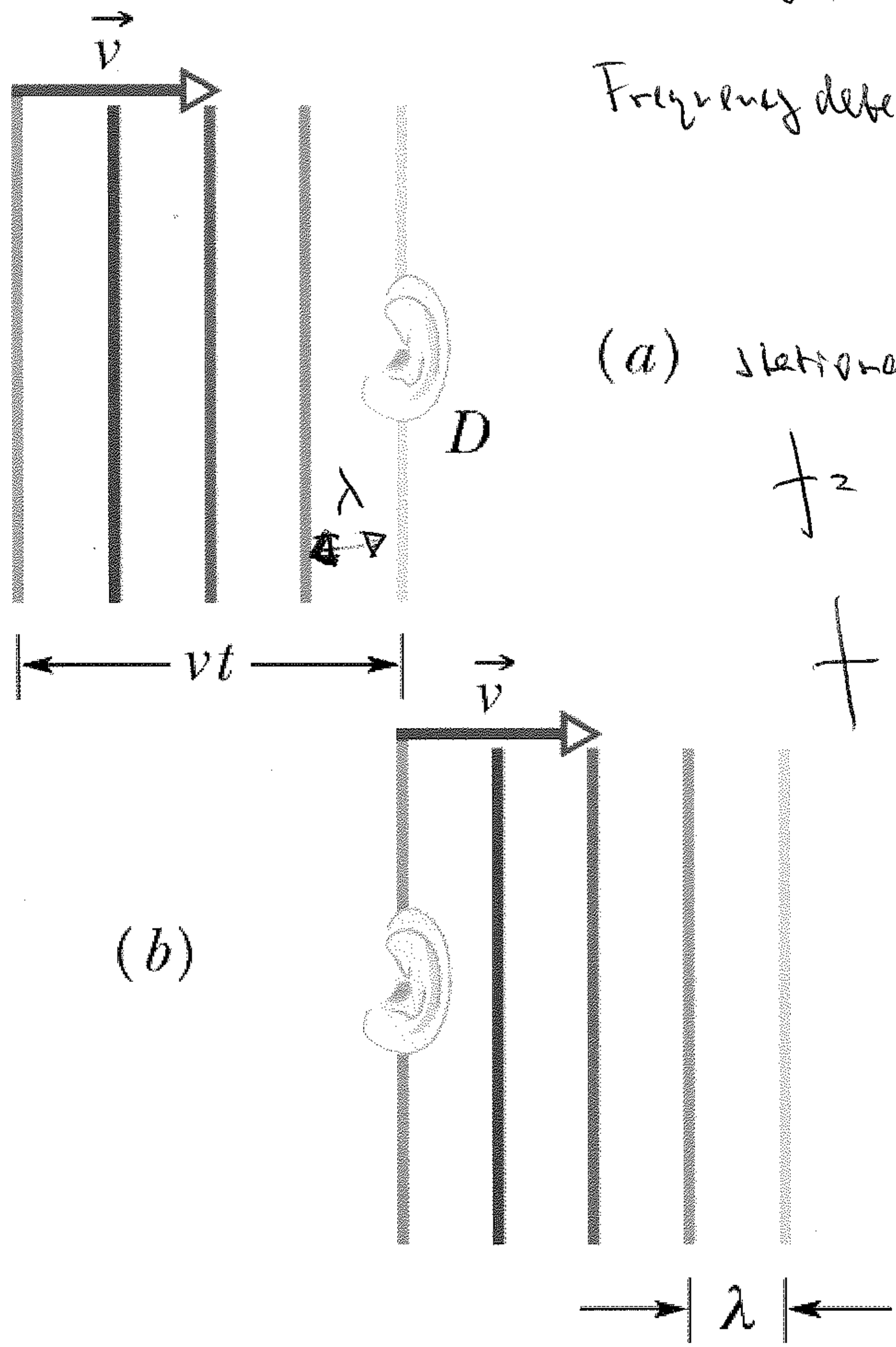
When source is moving to right, Joe hears a lower frequency (longer wavelength) than does Linda.



(b) Source moving with speed v_s

(11) Detector moving, source stationary

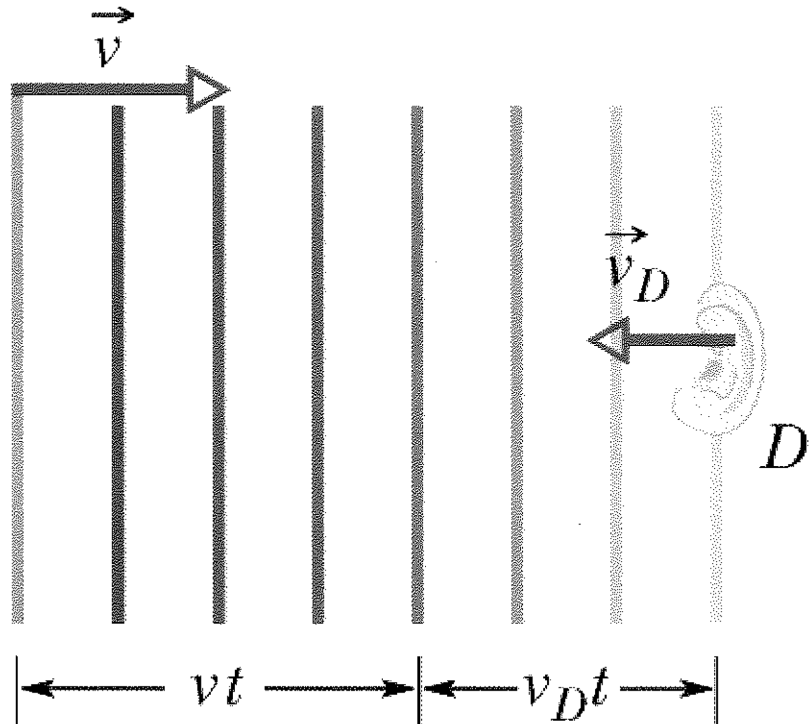
Frequency detected - The rate at which the detector intercepts wavefronts.



(a) stationary

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

$$f = \frac{\#\text{events}}{\text{time}}$$

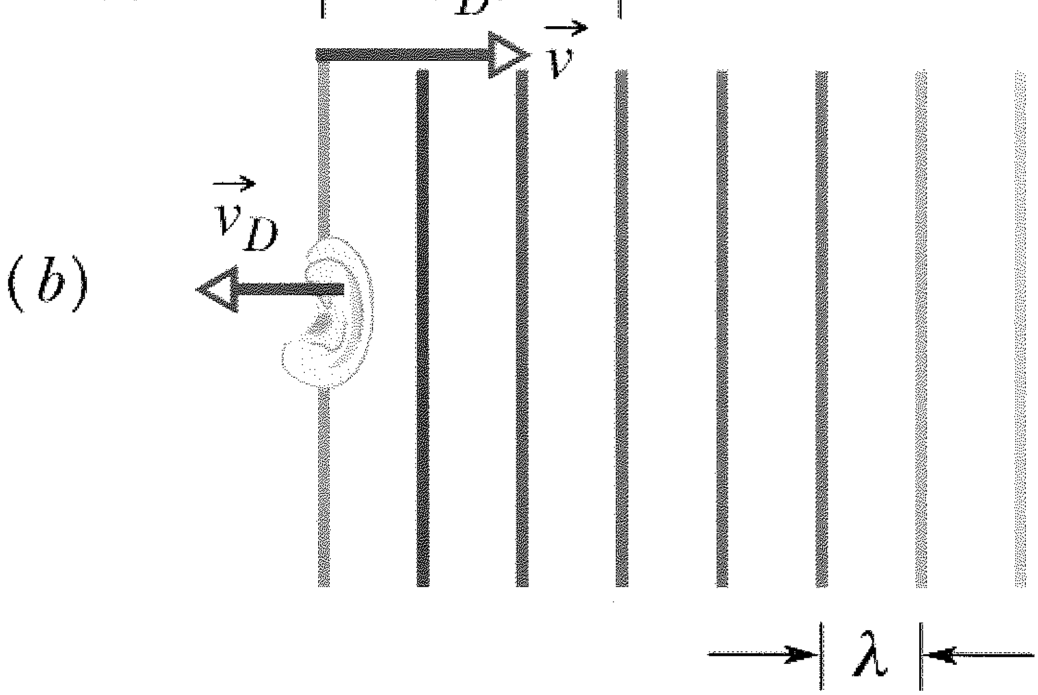


$$f' = \frac{(vt + v_D t)/\lambda}{t} = \frac{v + v_D}{\lambda}$$

and $\lambda = v/f = v \cdot T$

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

$f' > f$



if Detector moves away from the source

$$\rightarrow \boxed{f' = f\,\frac{v - v_D}{v}} \quad f' < f$$

Dividing the numerator and denominator by v leads to

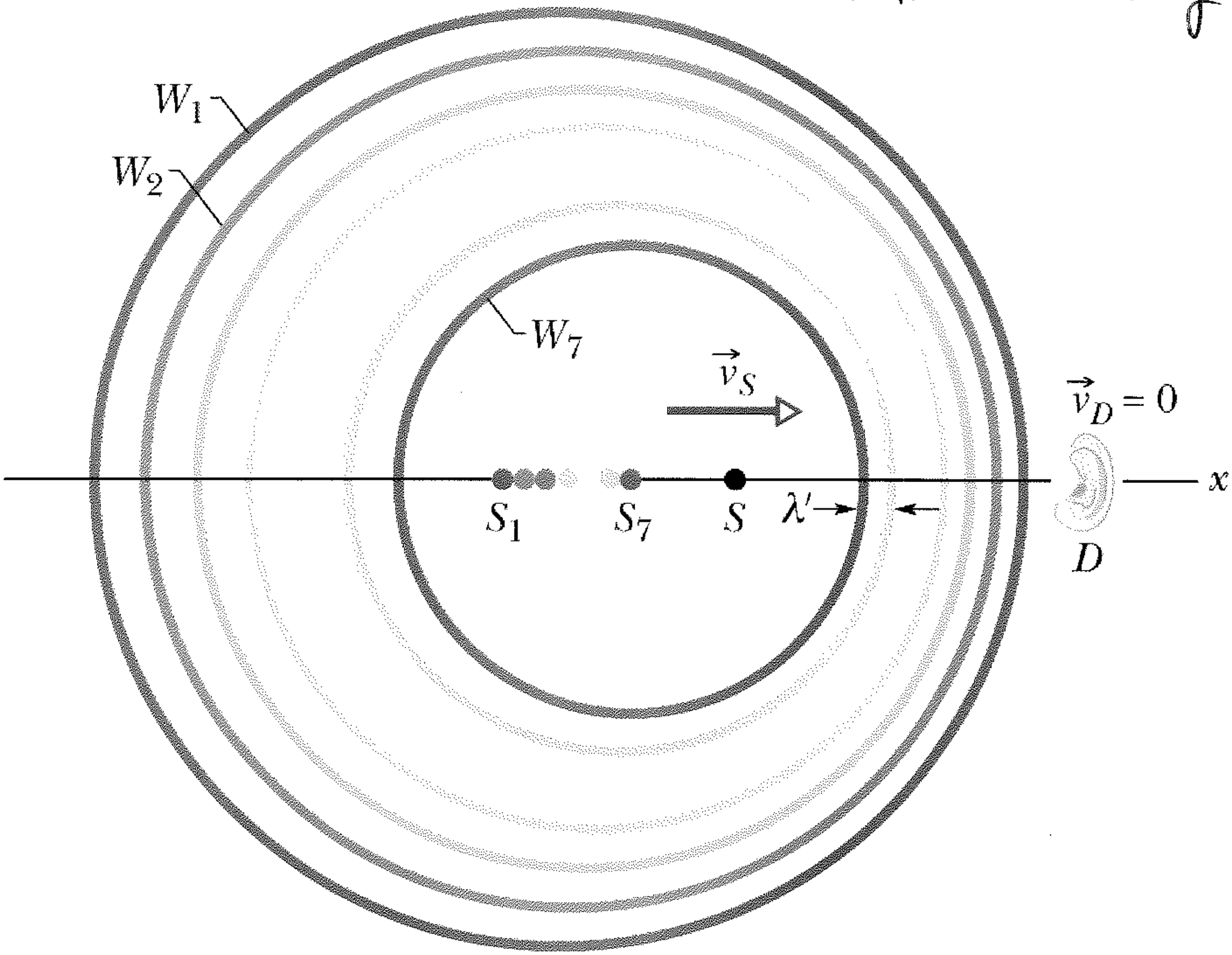
$$f' = \frac{f}{1 - v_S/v} \qquad \text{(Doppler effect, source approaching; SI unit: Hz)} \tag{11.7}$$

When $v_s < v$, Equation 11.7 shows that the perceived frequency f' is greater than the source frequency f. Joe's situation is analogous, now with the wavelength *increased* by v_sT, giving a perceived frequency

$$f' = \frac{f}{1 + v_S/v} \qquad \text{(Doppler effect, source receding; SI unit: Hz)} \tag{11.8}$$

Here $f' < f$, so Joe hears a lower frequency. All this agrees with your experience with the passing fire truck.

Source moving; Detector stationary



Let W_1 and W_2 are emitted in T

$\lambda = V.T$ if nothing moves

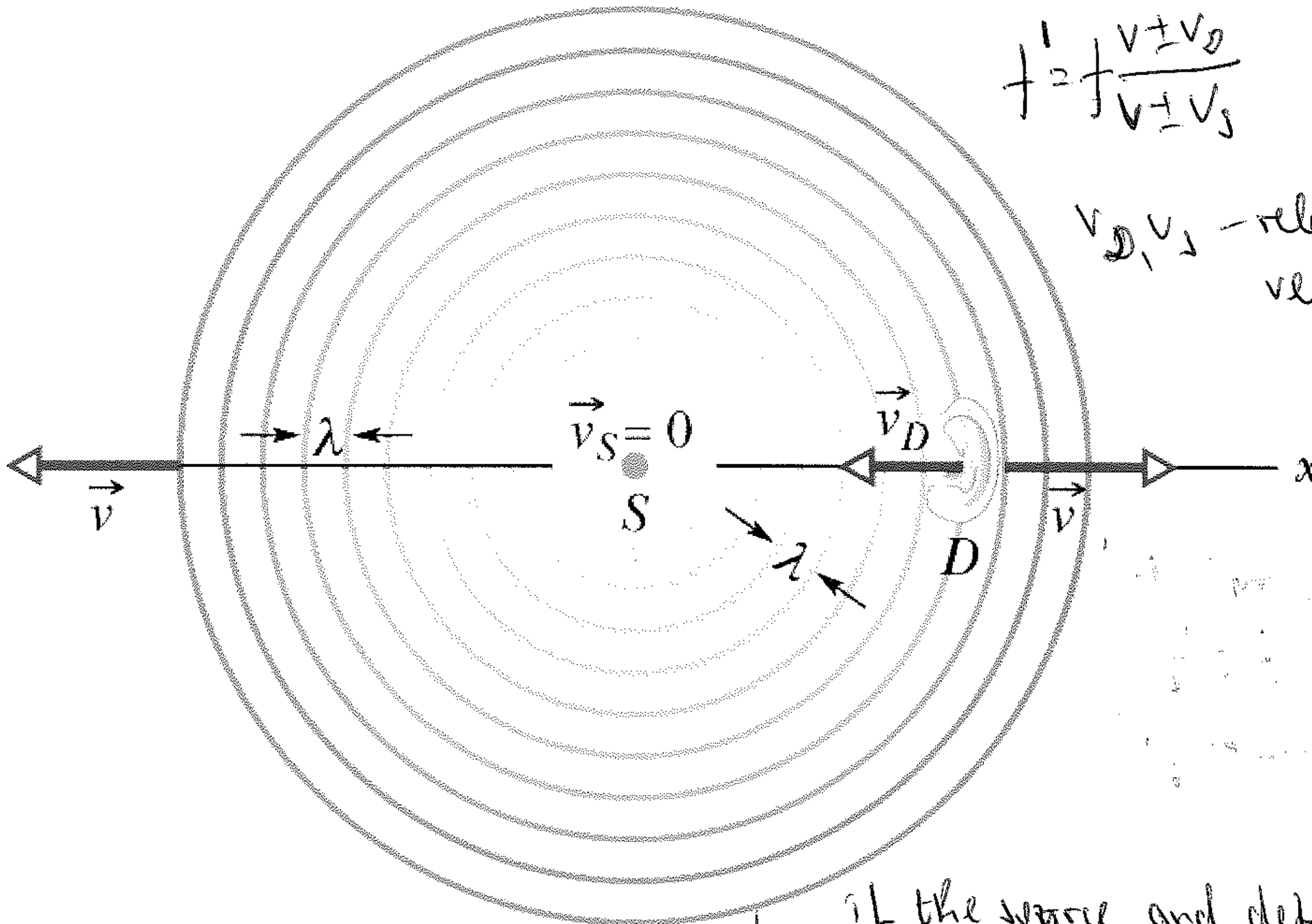
$\lambda' = V.T - V_s.T$ if the source moves

$$\rightarrow f' = \frac{V}{\lambda'} = \frac{V}{VT - V_sT} = \frac{V}{V/f - V_s/f} = \boxed{f \cdot \frac{V}{V - V_s}} ; f' > f$$

if the source moves away

$$\boxed{f' = f \cdot \frac{V}{V + V_s}} ; f' < f$$

The Doppler effect



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

v_D, v_S – relative velocities

How to get the sign right?

If the source and detector come closer $f' > f$, otherwise $f' < f$.

51. A stationary source generates 5.0 Hz water waves whose speed is 2.0 m/s. A boat is approaching the source at 10 m/s. The frequency of these waves, as observed by a person in the boat, is:

1) 5.0 Hz
2) 15 Hz
3) 20 Hz
4) 25 Hz
5) 30 Hz

$f = 5$ Hz | $f' = ?$

$V_o = 10$ m/s

An cruise ship is approaching a harbor at a speed of 10 m/s. The captain sounds 100 Hz whistle. The air is still and the speed of sound in air is 343 m/s. What is the frequency of the ship whistle tone heard in the harbor ?

By definition $f' = f/(1 - v_s/v_a)$ where $v_s = 10$ m/s, $v_a = 343$ m/s and f = 100 Hz

Therefore $f' = 100 \text{ Hz} / (1- 10 / 343) = 100 / (0.97) = 103.1$ Hz jet $f = 850$ Hz | $f' = ?$ $232\ \frac{m}{s}$; $v_s = 343\ \frac{m}{s}$

$f' = ?$ $232\ \frac{m}{s}$

70. ORGANIZE AND PLAN The expression for the observed frequency f' when the source is in relative motion to the medium (where the observer is stationary with respect to the medium) is:

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

$$f' = \frac{f}{1 \mp v_s/v} \times V = \frac{f \cdot v}{v \pm v_s}$$

where f is the emitted frequency of sound, v is the speed of sound in the medium, $-v_s$ corresponds to the velocity of the source approaching the observer, and $+v_s$ corresponds to the velocity of the source receding away from the observer.

We are given f and v_s in this problem.

SOLVE Observed frequency of sound when the jet approaches at 232 m/s:

$$f' = \frac{850\ \text{Hz}}{1 - (232\ \text{m/s})/(343\ \text{m/s})} = 2630\ \text{Hz}$$

Observed frequency of sound when the jet recedes at 232 m/s:

$$f' = \frac{850\ \text{Hz}}{1 + (232\ \text{m/s})/(343\ \text{m/s})} = 507\ \text{Hz}$$

REFLECT The jet is traveling at roughly 70% the speed of sound. The sound when approaching differs from the receding sound by roughly 2.5 octaves. Remember this the next time you hear a fighter plane fly toward you.

$f = ?\ \xrightarrow{13\ \frac{m}{s}}\ \xleftarrow{13\ \frac{m}{s}}$ $\quad$ $\rightarrow f' = 257\ Hz$; $V_s = 343\ \frac{m}{s}$

73. ORGANIZE AND PLAN As in the previous problem, we use the relationship:

$f' = f\frac{V}{V \pm V_s}$ $\longrightarrow$ $$f' = \frac{f}{1 \mp v_s/v}$$

where f is the emitted frequency of sound, v is the speed of sound in the medium, $-v_s$ corresponds to the velocity of the source approaching the observer, and $+v_s$ corresponds to the velocity of the source receding away from the observer.

We are given v_s and f' in this problem. Isolating to find f if the source is approaching the observer:

$13\ \frac{m}{s} = V_s$

$$f = f' \times (1 - v_s/v)$$

In the second part of the problem, we use the result from the first part and apply

$13\ \frac{m}{s} = V_s$

$$f' = \frac{f}{1 + v_s/v}$$

SOLVE The emitted frequency of the squawk:

$$f = 257\ \text{Hz} \times (1 - (13\ \text{m/s})/(343\ \text{m/s})) = 247\ \text{Hz}$$

Observed frequency as goose is receding:

$$f' = \frac{247\ \text{Hz}}{1 + (13\ \text{m/s})/(343\ \text{m/s})} = 238\ \text{Hz}$$

REFLECT These differences are noticeable. The difference in frequency between approaching goose and receding goose corresponds approximately to adjacent keys on the piano.

$V = 343 \frac{m}{s}$

78. ORGANIZE AND PLAN The expression for the observed frequency f' when the source is in relative motion to the medium (where the observer is stationary with respect to the medium) is:

$$f' = \frac{f}{1 \mp v_s/v}$$

$f' = \frac{f}{1 - V_s/V} \rightarrow \frac{f'}{f} = \frac{1}{1 - \frac{V_s}{V}} = 2$

For the observed frequency to be twice that of the emitted frequency the object must be approaching and the following condition must hold:

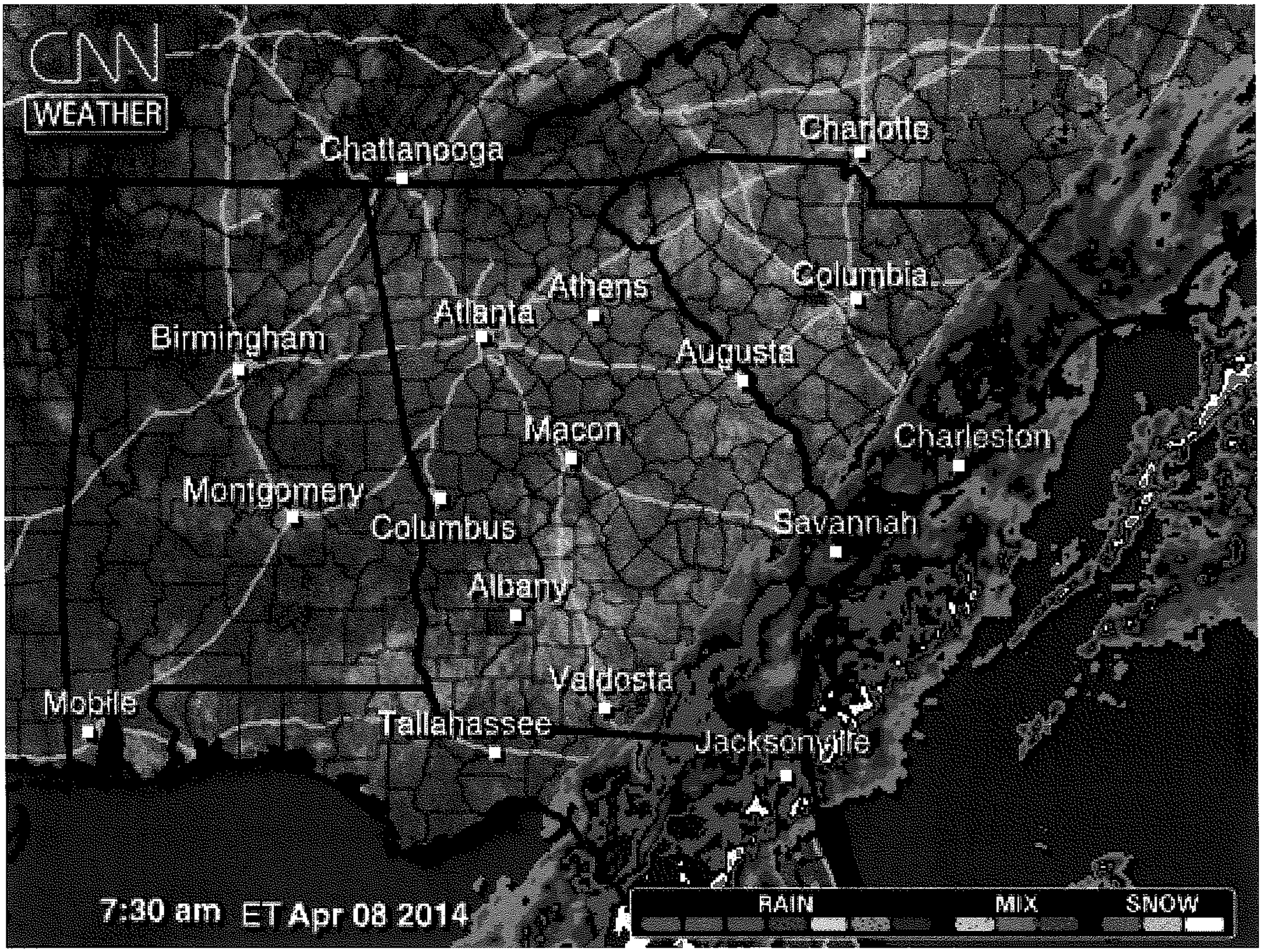
$f'/f = 2 = \frac{1}{\left(1 - \frac{V_s}{V}\right)} \Rightarrow \left(1 - \frac{V_s}{V}\right) = 0.5$

$$1 - v_s/v = 0.5$$

$1 - 0.5 = \frac{V_s}{V} \rightarrow V_s = V \times 0.5 = \frac{V}{2}$

$$v_s = v/2$$

SOLVE The source would have to move half of the velocity of the wave in the medium. In air, this velocity is 172 m/s.


CNN
WEATHER
Chattanooga
Charlotte
Athens
Columbia
Atlanta
Birmingham
Augusta
Macon
Charleston
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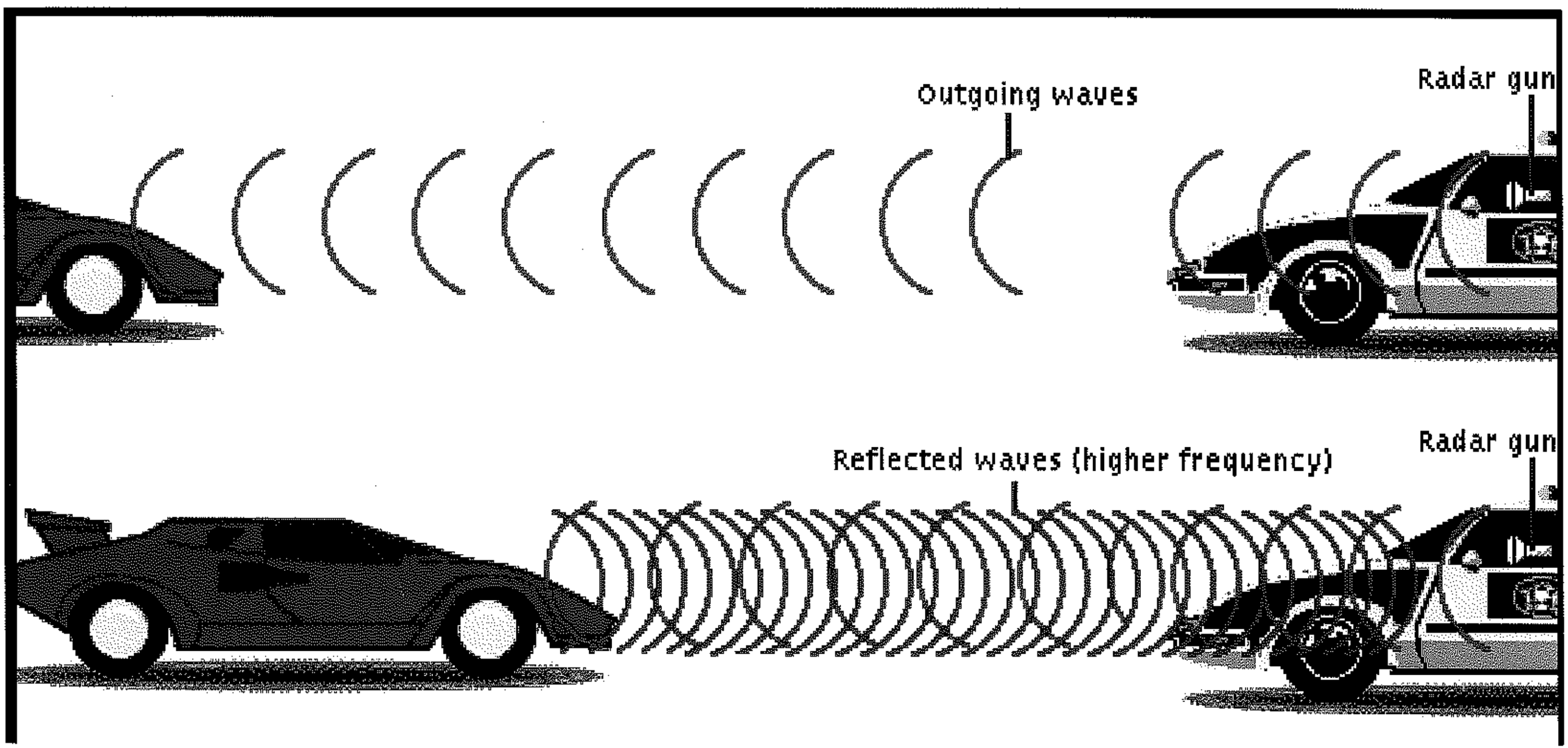
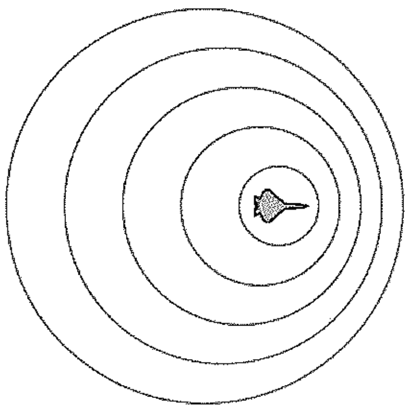
RAIN
MIX
SNOW


Outgoing waves
Radar gun
Reflected waves (higher frequency)
Radar gun

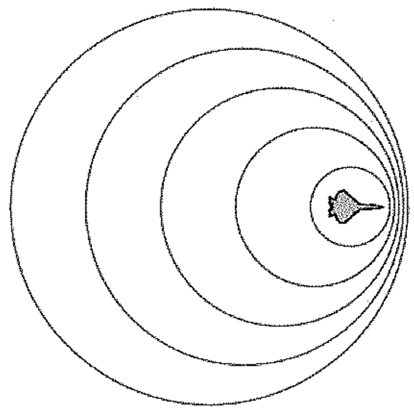

REUTERS

Figure 11.19

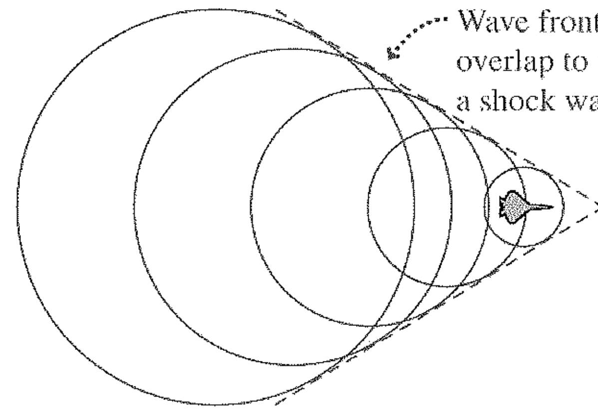
Shock waves and Sonic Booms



(a) Flying at normal speed



(b) Flying at just below speed of sound

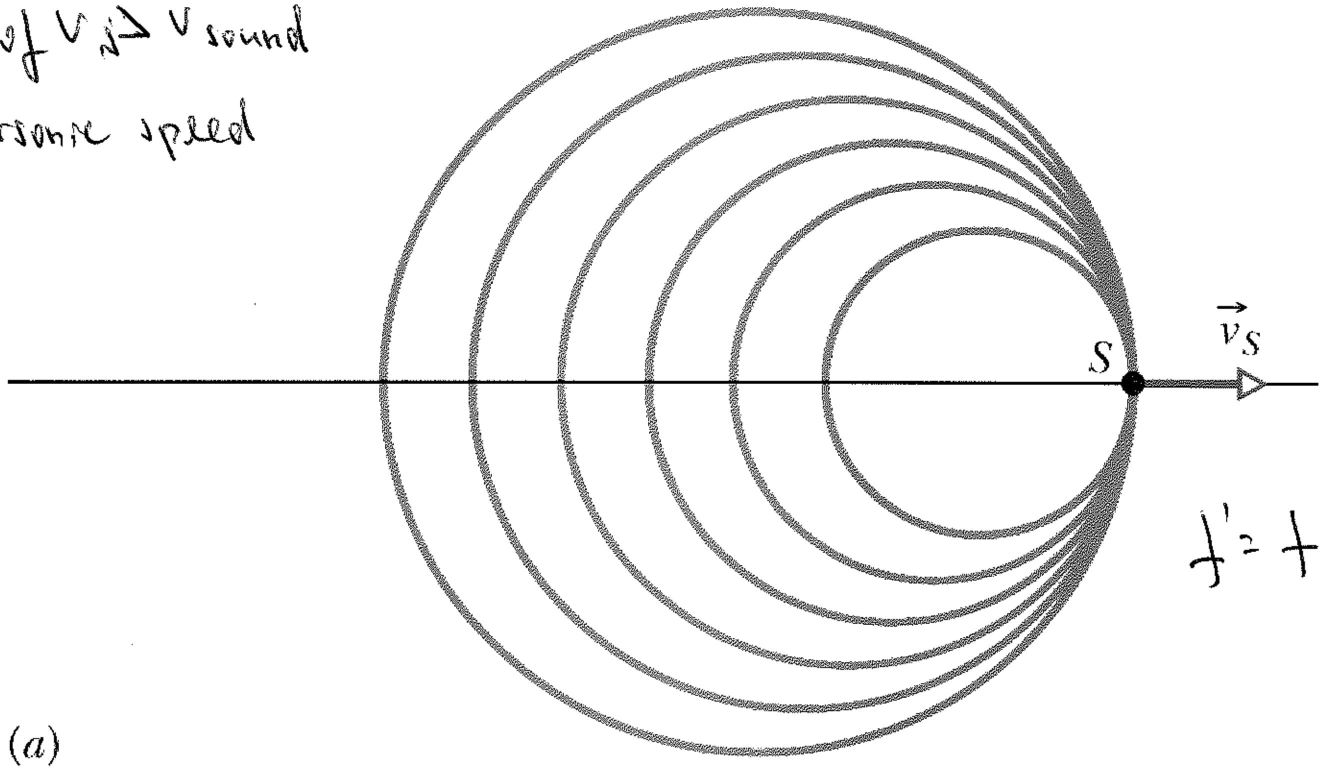


(c) Flying at supersonic speed

supersonic speed.

Case of $v_s > v_{sound}$

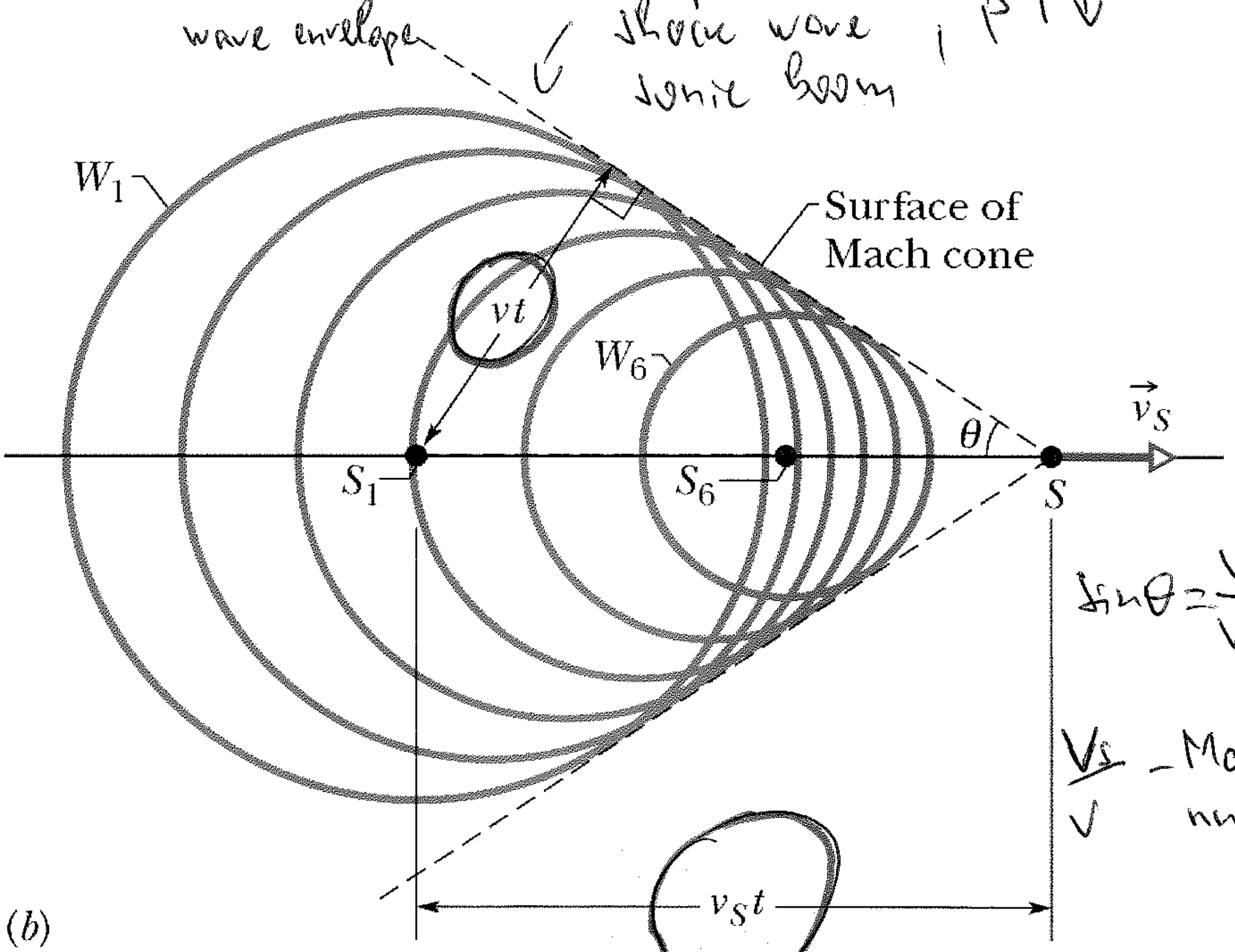
supersonic speed



$$f' = f\frac{v}{v - v_s}$$

(a)

$\sum \Delta p \sim p_0$



$$\sin\theta = \frac{vt}{v_s t} = \frac{v}{v_s}$$

$\frac{v_s}{v}$ – Mach number

(b)

Image:FA-18 Hornet breaking sound barrier (7 July 1999).jpg

From Wikipedia, the free encyclopedia

Image File history File links

$f' = ?$
$\downarrow$ 4 sec 425 Hz | free fall $\Rightarrow$ $V = \cancel{V_0} + gt$

75. ORGANIZE AND PLAN To determine the observed frequency from the stationary helicopter we must know the velocity of the source (the parachutist). Recall kinematic equations for free-fall. After time t the velocity is $v = gt$ for constant acceleration. With the deduced velocity we employ the Doppler effect relation for a receding source:

$f' = f \frac{V}{V \pm V_s}$ | $\rightarrow$ $$f' = \frac{f}{1 + v_s/v}$$ $V = g \cdot t$

In this problem:

$$f' = \;\; = \frac{f}{1 + \frac{V_s}{V}} = \frac{f}{1 + \frac{g \cdot t}{V}} = \frac{425\ \text{Hz}}{1 + \frac{9.82 \times 4}{343}}$$

SOLVE Plugging in values:
The observed frequency of the shout is

$$= 414\ \text{Hz} =$$

REFLECT The frequency is diminished as expected and the effect is noticeable. The glissando of the falling man is embedded in our cultural experience. What you hear in movies (or mimic with your voice when you are pretending you are falling) is a mixture between the Doppler effect and free-fall under constant acceleration.

$f' = f \cdot \frac{v + v_o}{v} = f\left(1 + \frac{v_o}{v}\right)$; $f' = 2f$

$1 + \frac{v_o}{v} = 2$

79. **ORGANIZE AND PLAN** From conceptual Exercise 11.13, the expression for the observed frequency f' when the source is stationary with respect to the medium and the observer is moving with respect to the source is:

$$f' = f(1 \pm v_o/v)$$

where v_o is the velocity of the observer and v is the velocity of the wave in the medium. The sign is positive for approaching and negative for receding.
To double the observed frequency the observer must be approaching the source and the following condition must be met:

$$(1 + v_o/v) = 2$$

$\frac{v_o}{v} = 1$

SOLVE Solving for v_o yields: $v_o = v$ To double the observed frequency when moving with respect to a stationary source you must travel the speed of sound in the medium.

$v_o = v = 343 \frac{m}{s}$