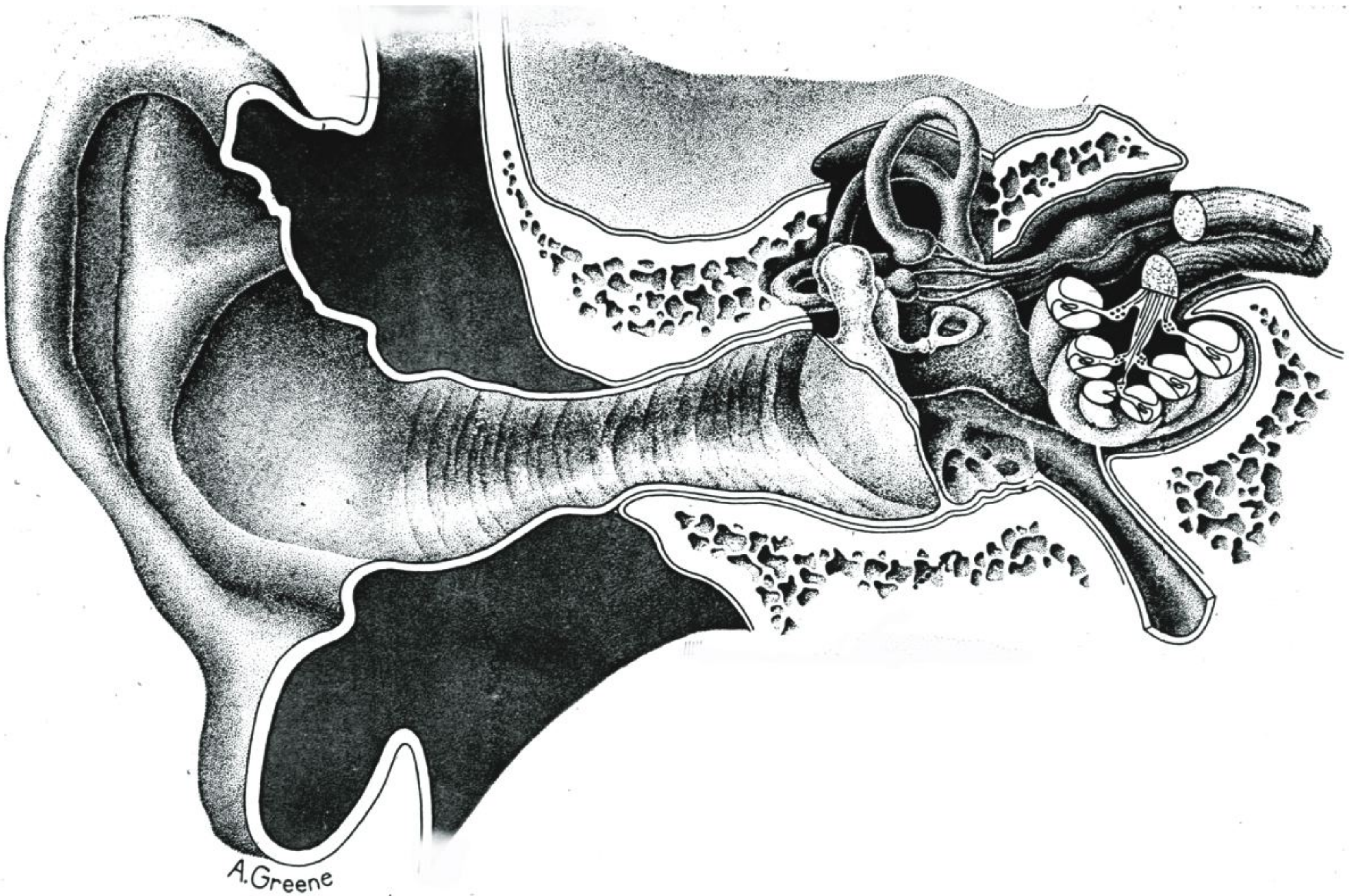
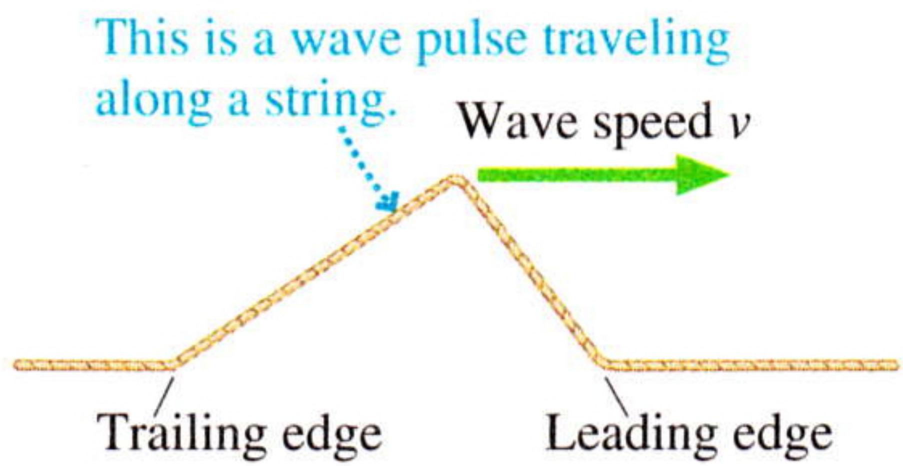
Waves, Sound, & Hearing

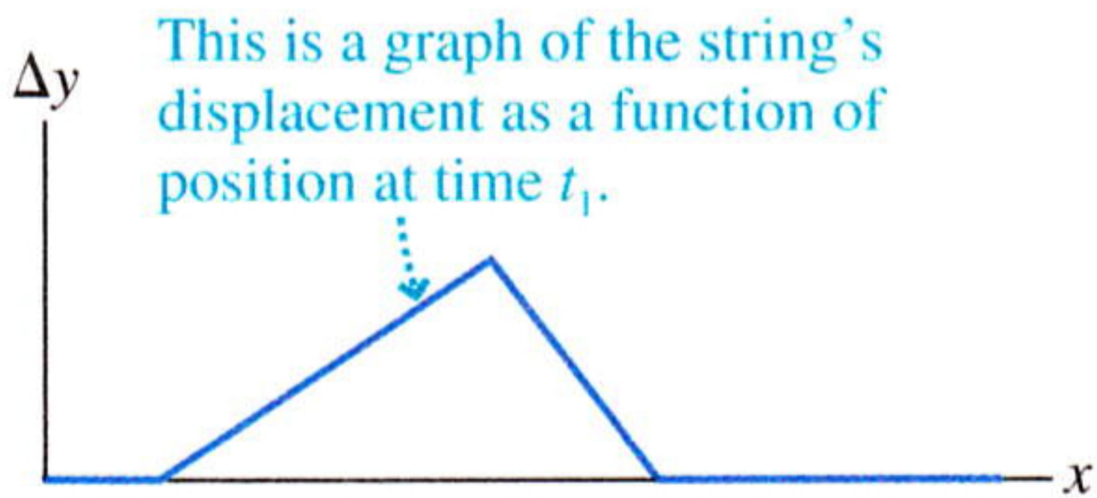
York University
Winter 2013
PHYS 1410 (3/26/13)

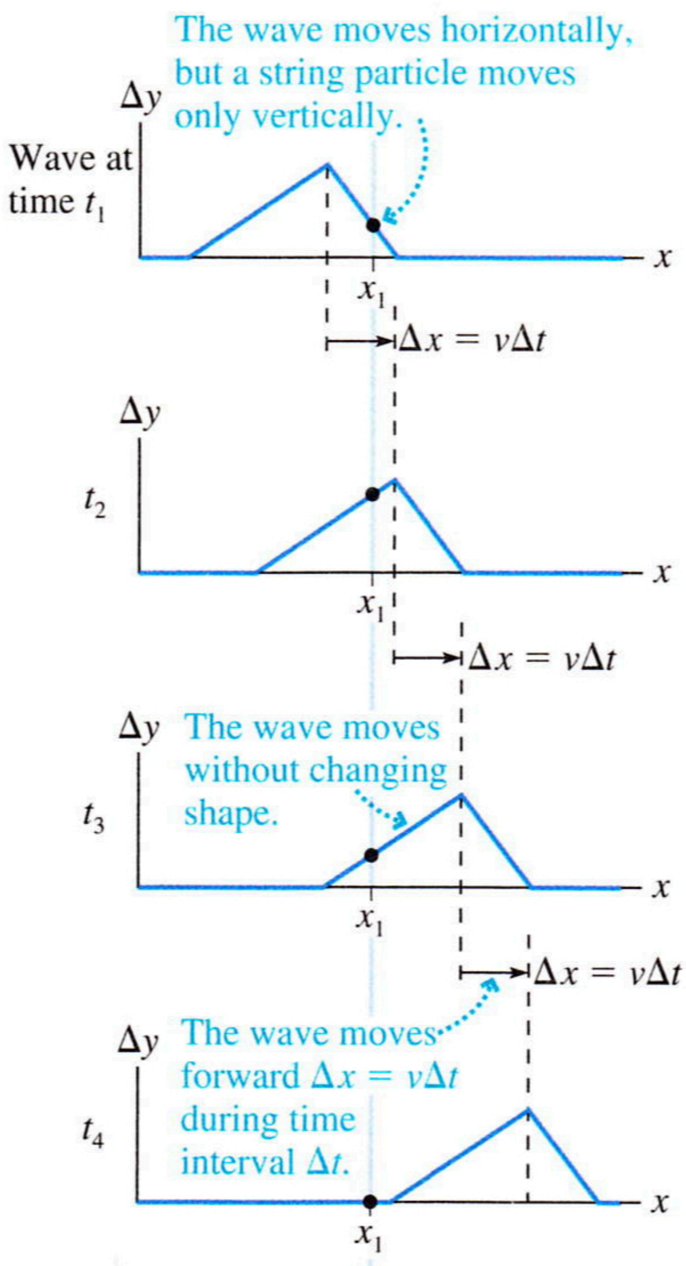
Reference/Acknowledgement:
Figures come from R. Knight (Physics: For Scientists & Engineers)
& from C. Bergevin


A.Greene

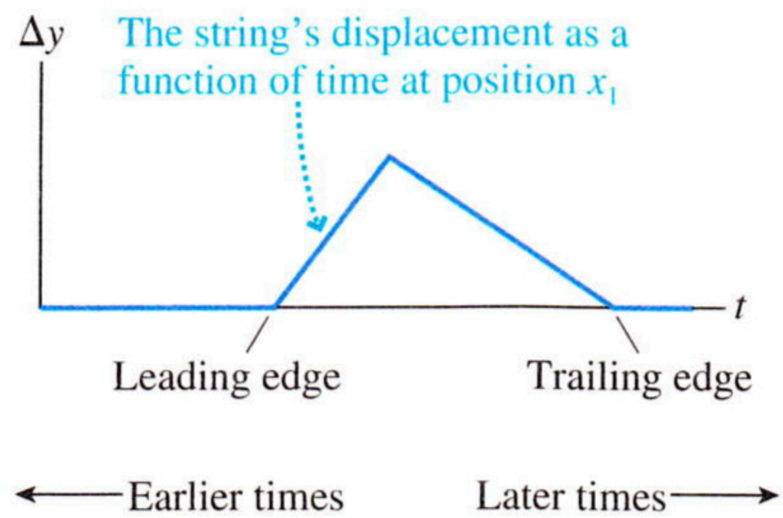
Further Background on Waves







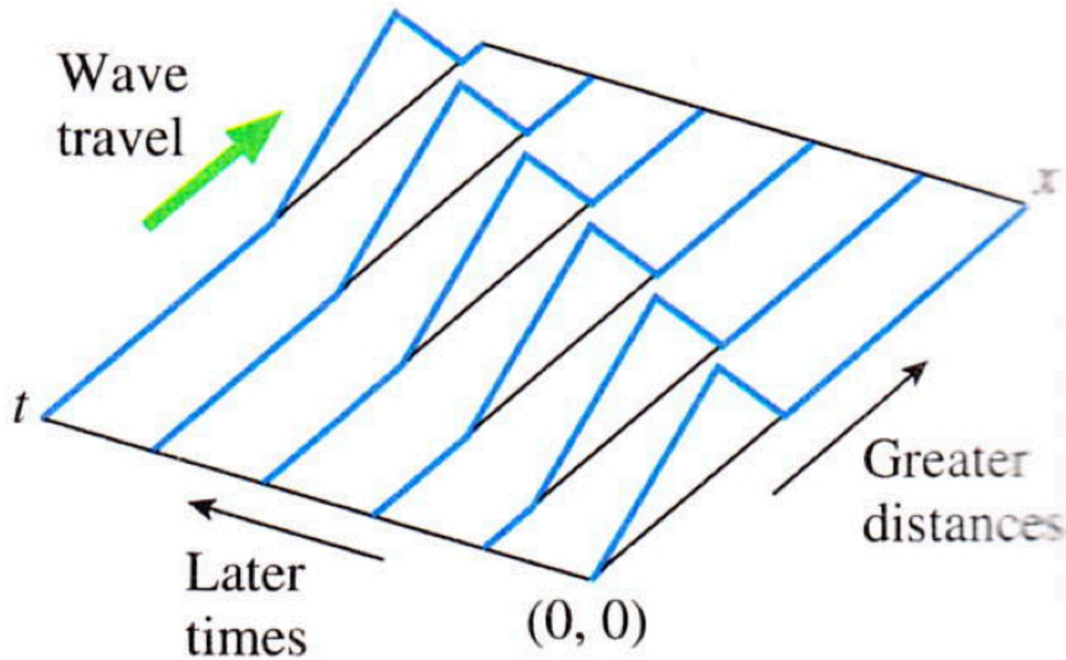
The wave moves horizontally, but a string particle moves only vertically.
Δy
Wave at time t_1
x
x_1
$\Delta x = v\Delta t$
Δy
t_2
x
x_1
$\Delta x = v\Delta t$
Δy
The wave moves without changing shape.
t_3
x
x_1
$\Delta x = v\Delta t$
Δy
The wave moves forward $\Delta x = v\Delta t$ during time interval Δt.
t_4
x
x_1



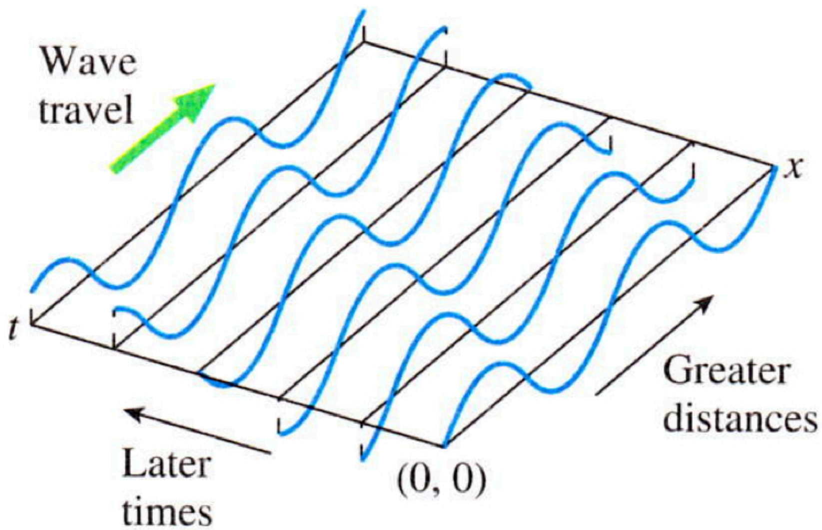
Δy
The string's displacement as a function of time at position x_1
t
Leading edge
Trailing edge
Earlier times
Later times

$$f(x,t) = f(x-vt)$$

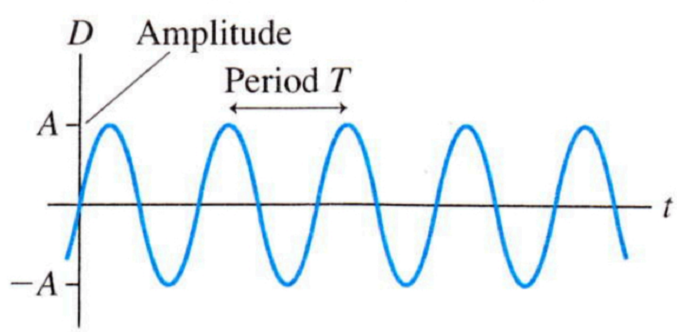
FIGURE 20.7 An alternative look at a traveling wave.



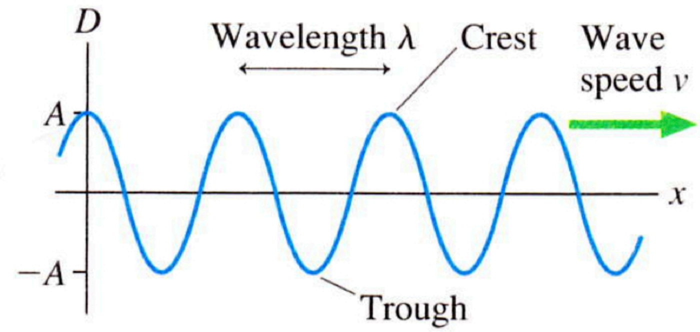
Sinusoidal Waves

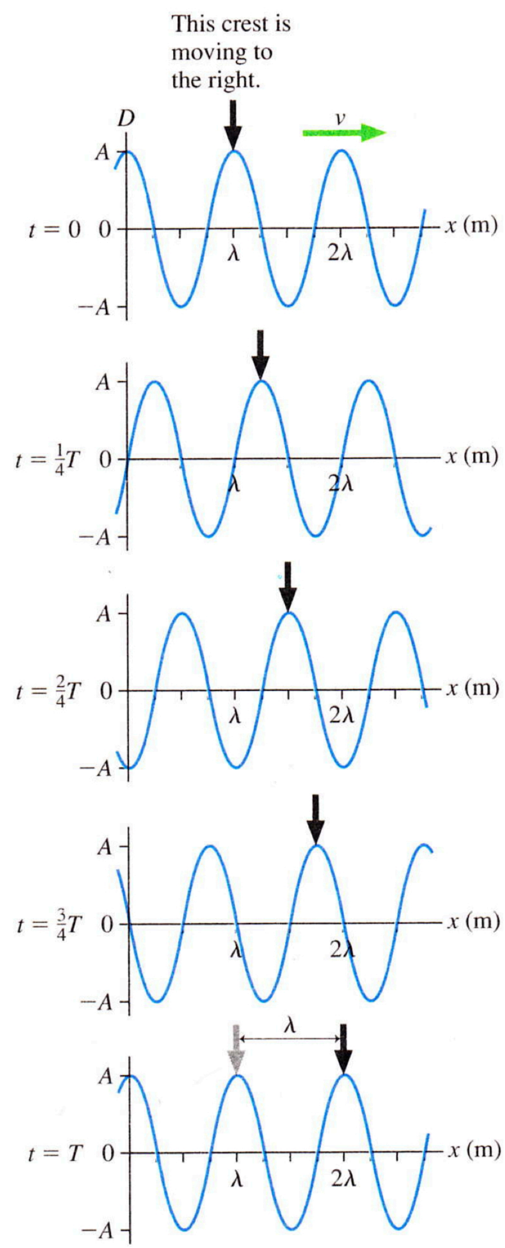


(a) A history graph at one point in space



(b) A snapshot graph at one instant of time

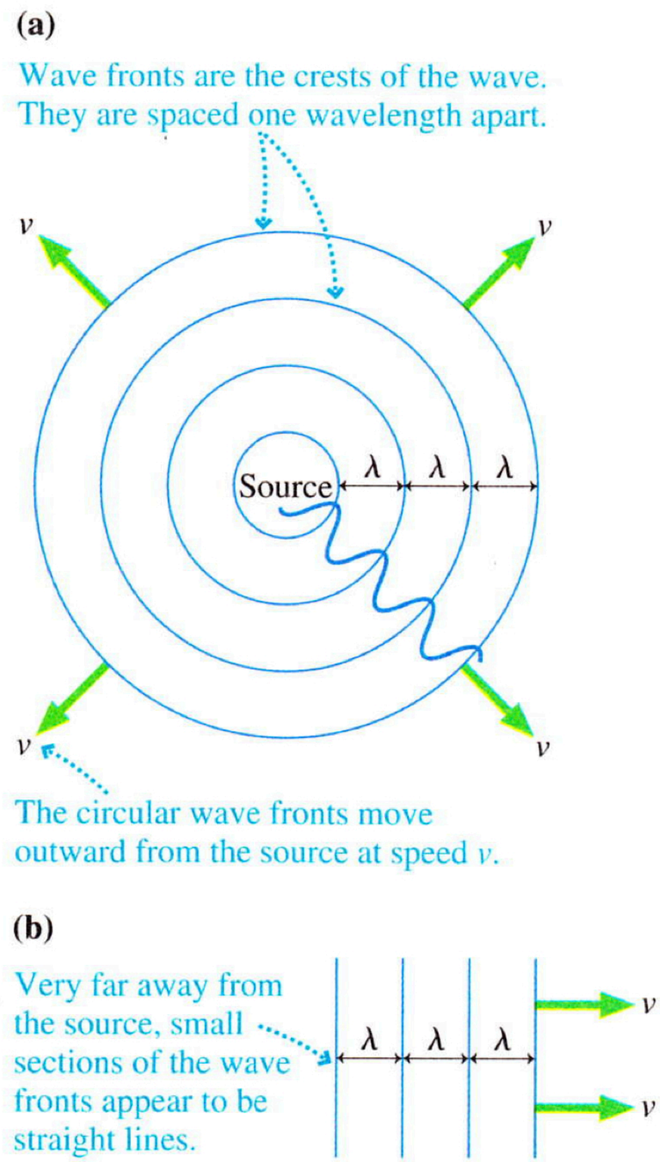




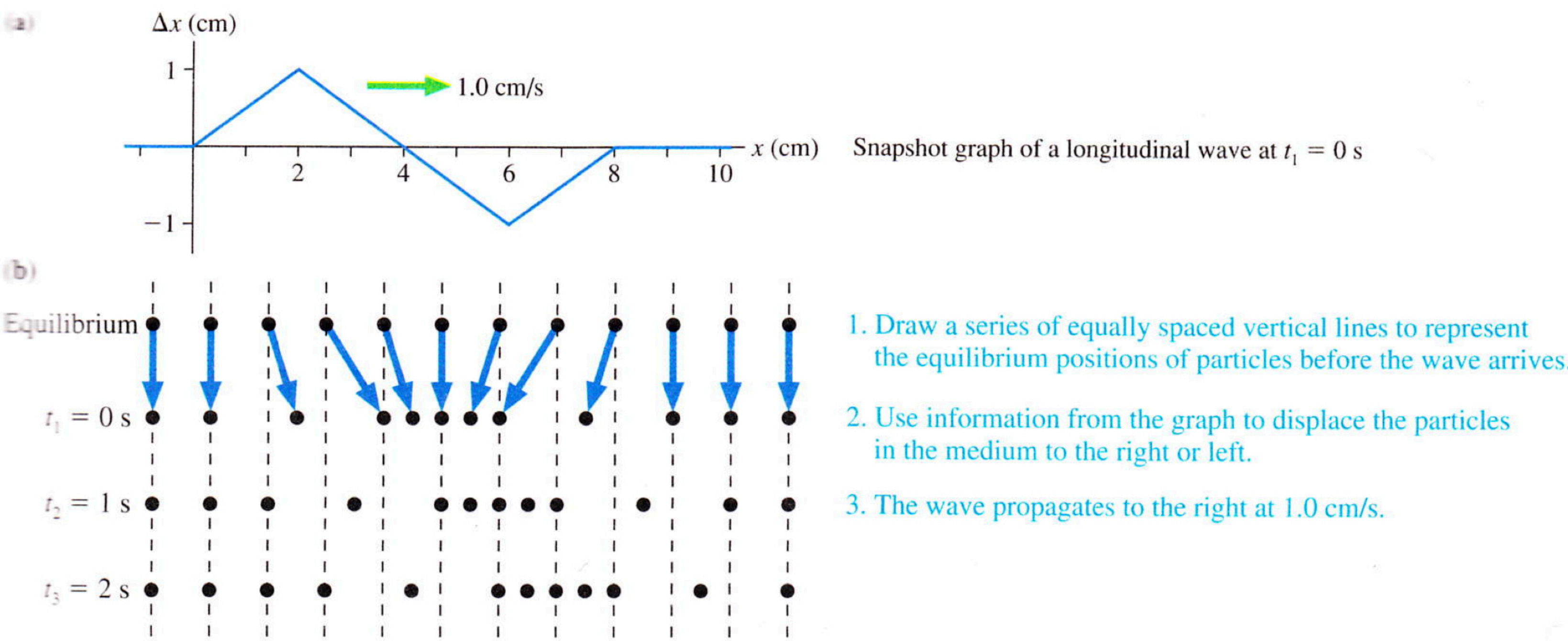
During a time interval of exactly one period, the crest has moved forward exactly one wavelength.

Circular/Spherical Waves

→ Note this is a 2-D wave
(i.e., higher # of dimensions!)

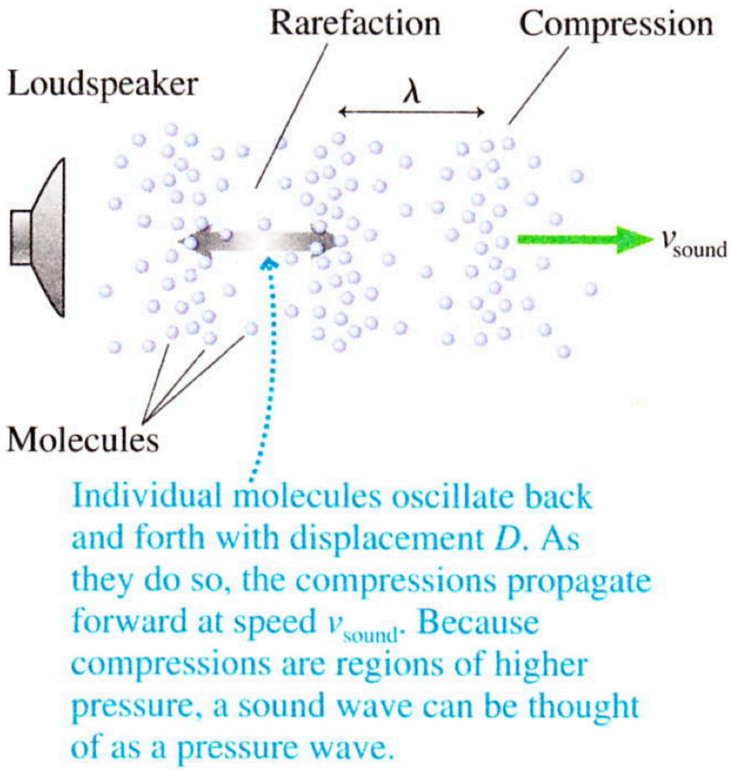


Longitudinal Waves



<u>Sound is a Longitudinal (Compression) Wave</u>

FIGURE 20.22 A sound wave in a fluid is a sequence of compressions and rarefactions. The variation in density and the amount of motion have been greatly exaggerated.

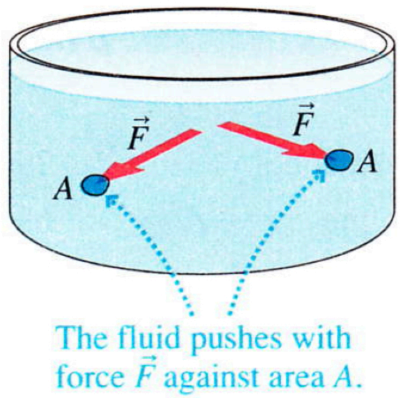


→ Notion of *pressure*

Pressure

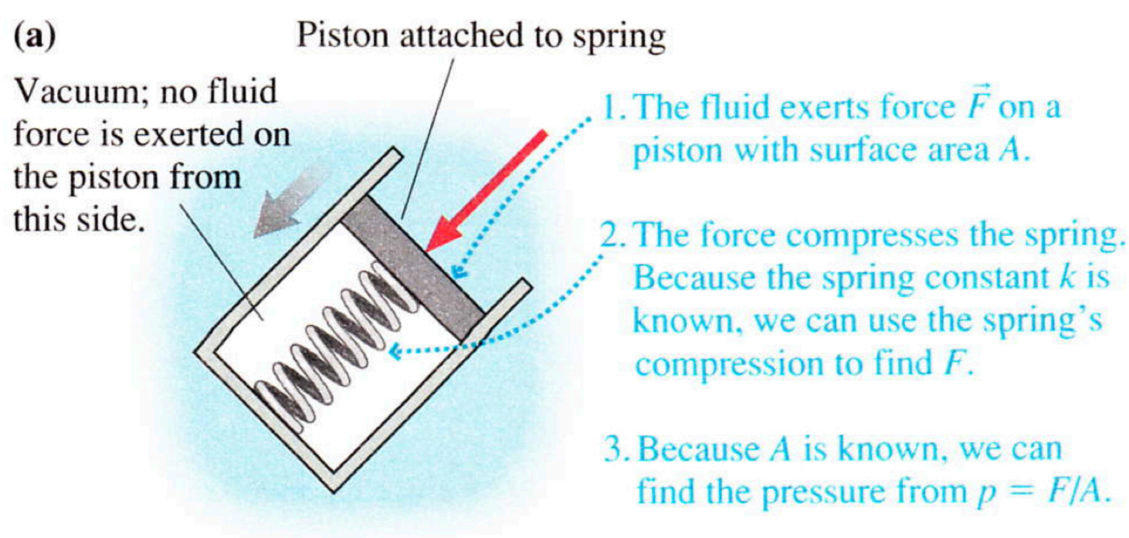
pressure = force/area

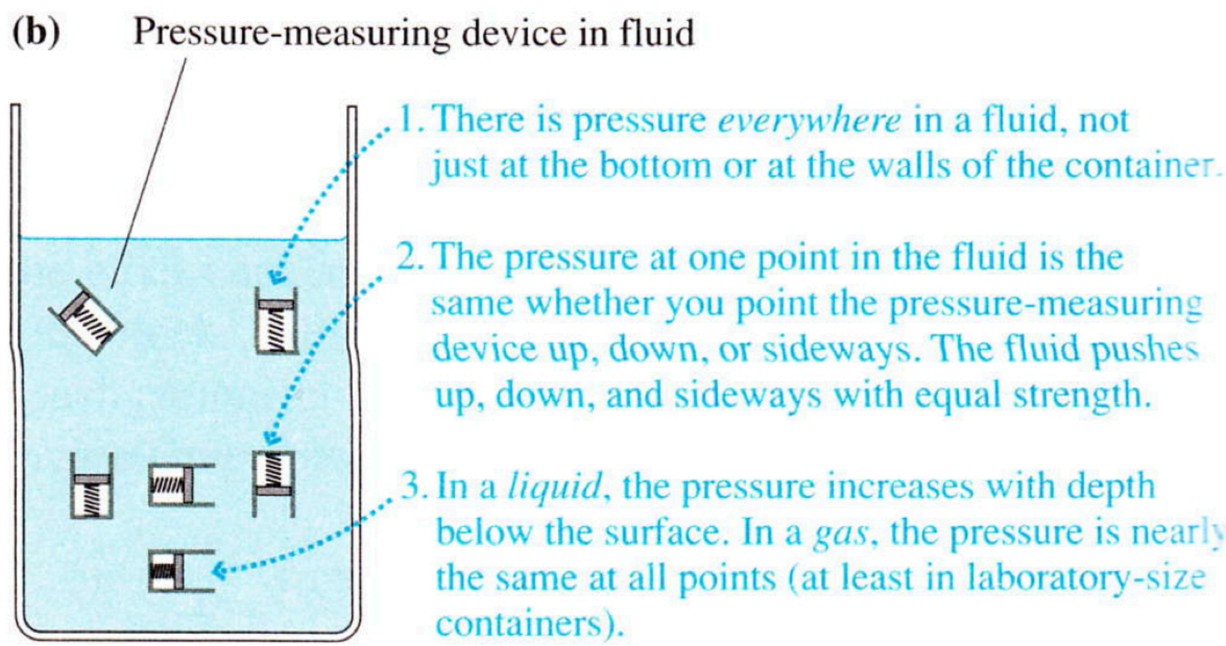
FIGURE 15.4 The fluid presses against area A with force $\vec{F}$.



Note: pressure is a scalar (not a vector)

[pressure] = pascal (Pa) = N/m^2




(b)
Pressure-measuring device in fluid
1. There is pressure *everywhere* in a fluid, not just at the bottom or at the walls of the container.
2. The pressure at one point in the fluid is the same whether you point the pressure-measuring device up, down, or sideways. The fluid pushes up, down, and sideways with equal strength.
3. In a *liquid*, the pressure increases with depth below the surface. In a *gas*, the pressure is nearly the same at all points (at least in laboratory-size containers).

<u>Microscopic Basis of Pressure</u>

FIGURE 15.7 The pressure in a gas is due to the net force of the molecules colliding with the walls.

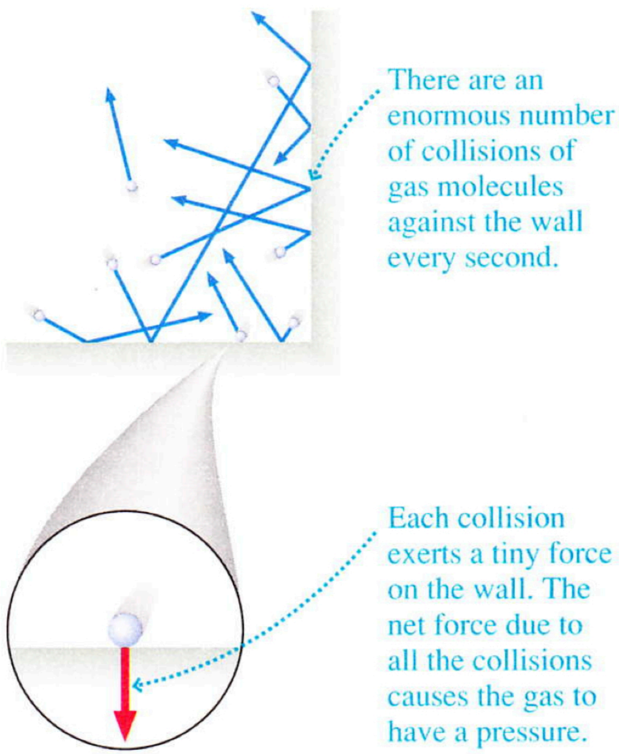
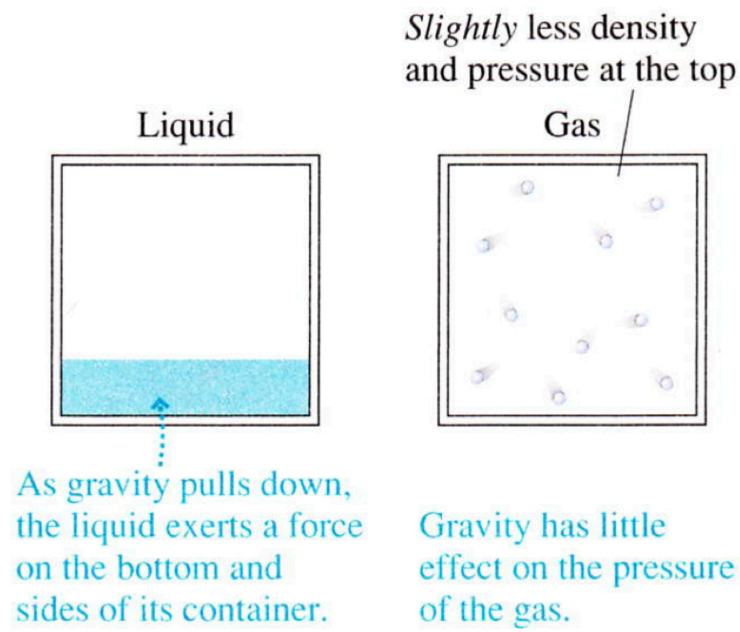
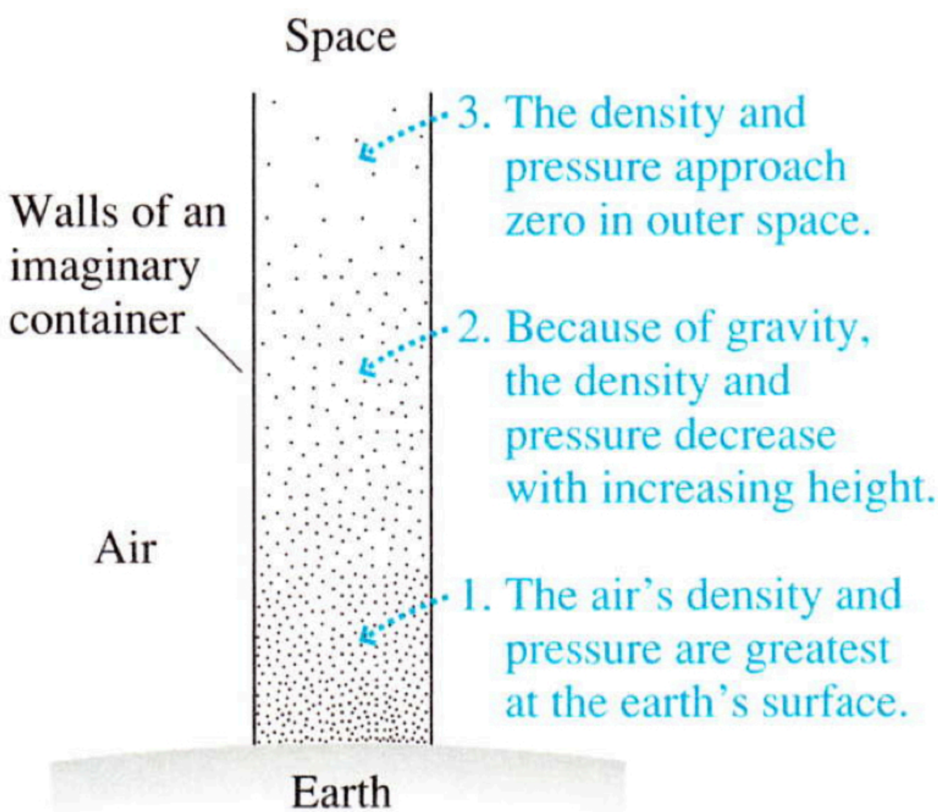


FIGURE 15.8 Gravity affects the pressure of the fluids.



Atmospheric Pressure

FIGURE 15.9 The pressure and density decrease with increasing height in the atmosphere.



Sound Pressure is a Variation Atop Atmospheric Pressure

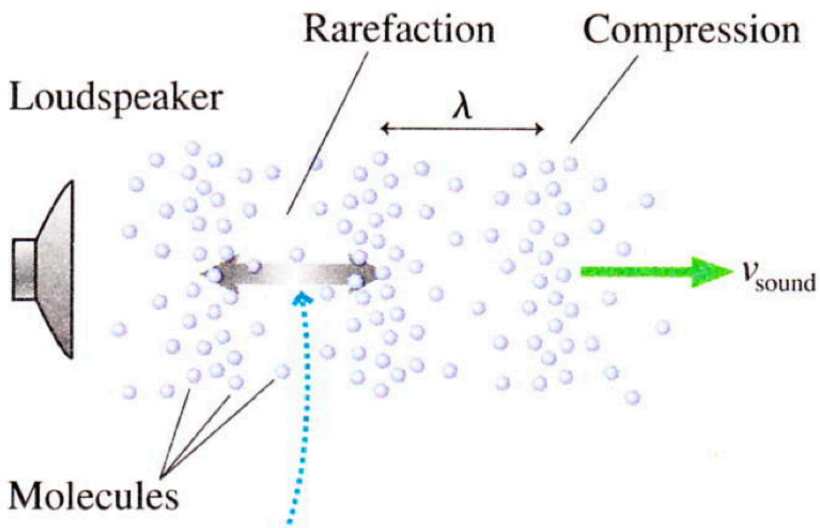
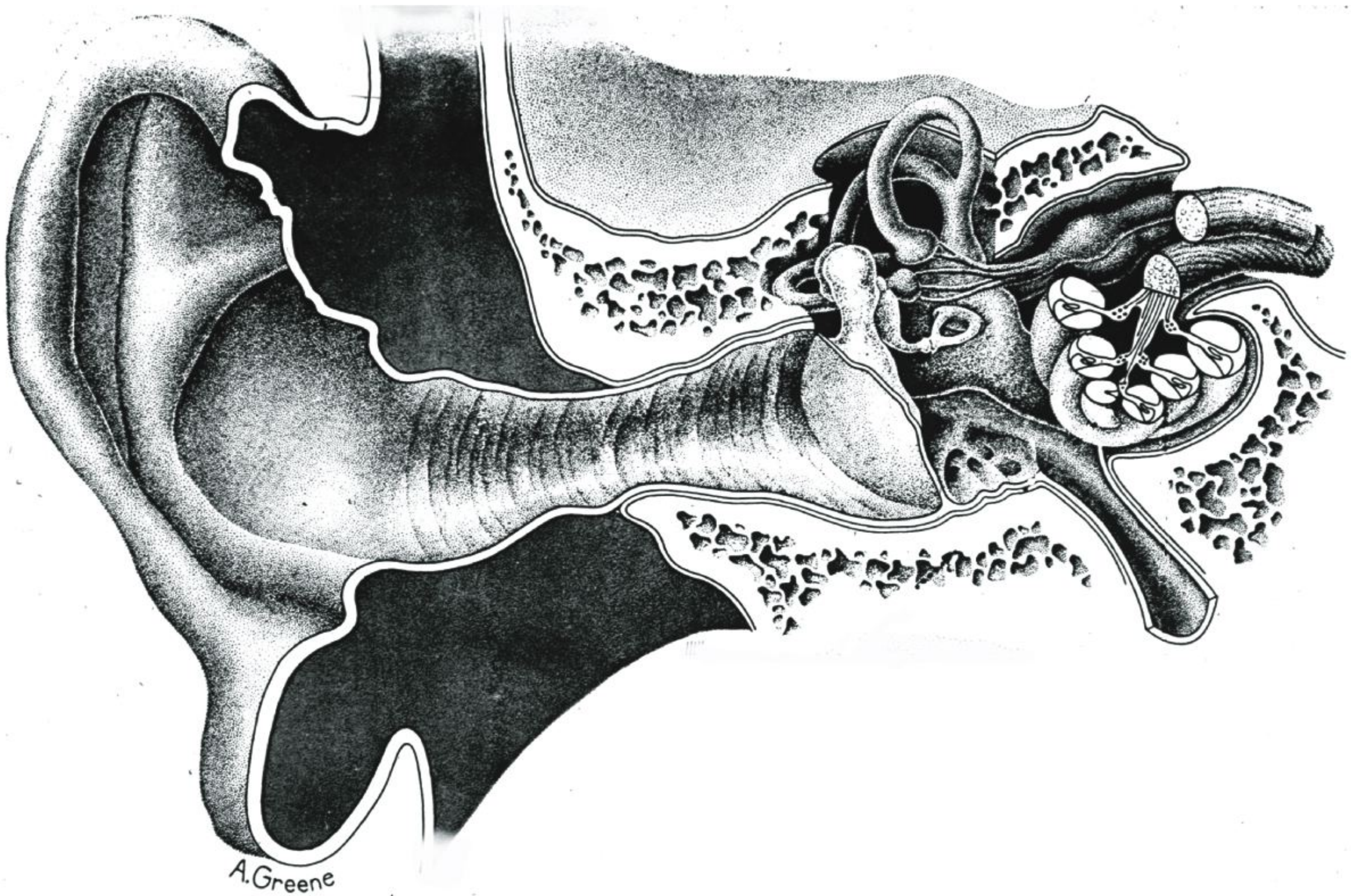


TABLE 20.1 The speed of sound

Medium	**Speed (m/s)**
Air (0°C)	331
Air (20°C)	343
Helium (0°C)	970
Ethyl alcohol	1170
Water	1480
Granite	6000
Aluminum	6420

Sound Can Be Used to 'Image'

Ultrasound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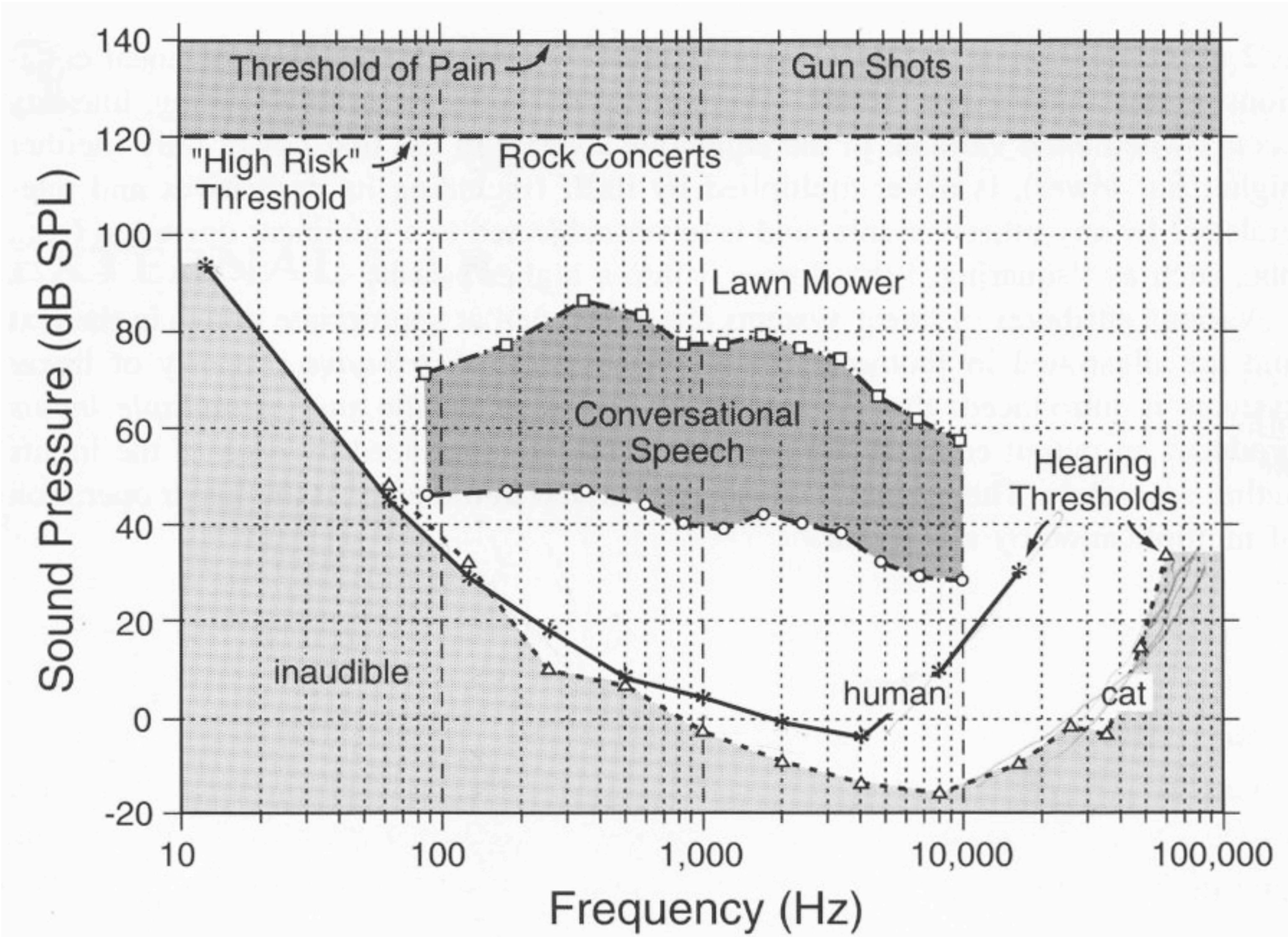
Human Audiogram



Audiogram indicates the sound pressure (dB SPL) required for detecting tones at different frequencies

Geisler (1998)

Decibels (dB)

$0\ dB = \times 1$

$10\ dB \approx \times 3$

$20\ dB = \times 10$

$40\ dB = \times 100$

$60\ dB = \times 1000$

$80\ dB = \times 10000$

$100\ dB = \times 100000$

...

- a dB value is a comparison of two numbers:

  $$dB = 20 \log(x/y)$$

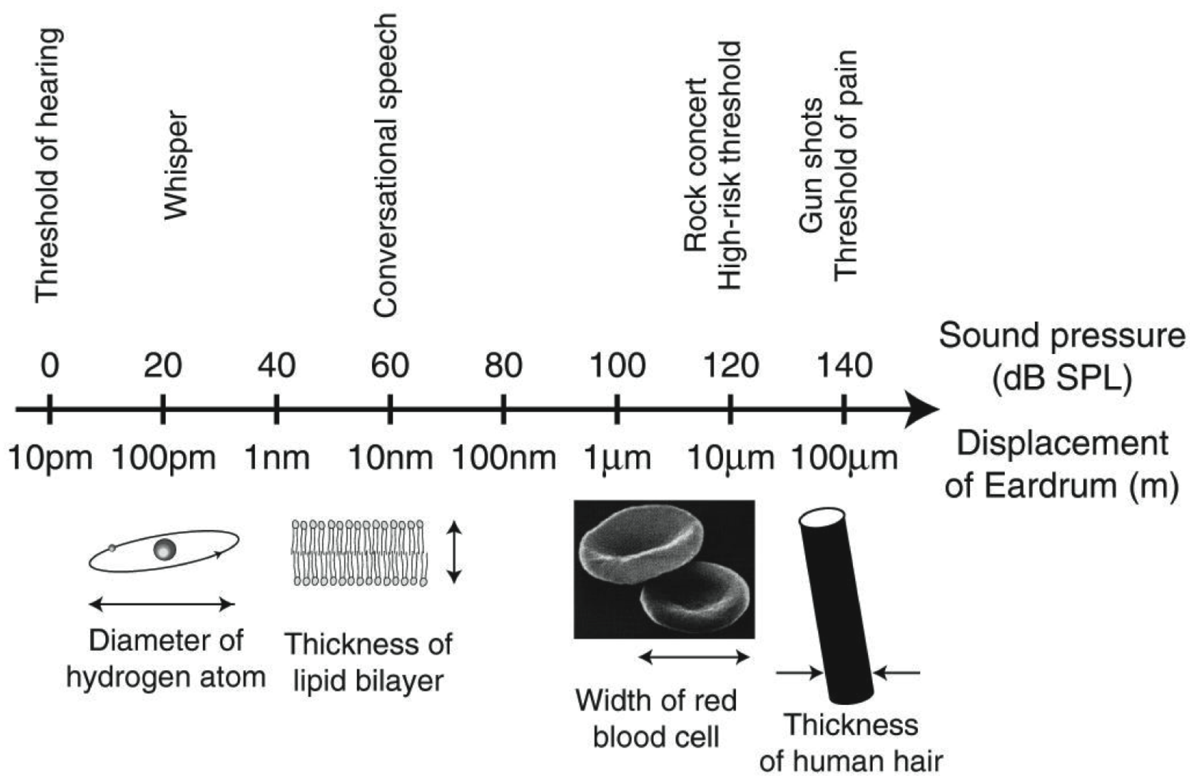
- A means to manage numbers efficiently

- 0 dB SPL = 20 μPa

⇒ But why do we need to use a dB scale?

Dynamic Range

Humans hear over a pressure range of 120 dB [that's a factor of a *million*]



D. Freeman

‘*The ear is capable of processing sounds over a remarkably wide intensity range, encompassing at least a million-fold change in energy….*’

P. Dallos

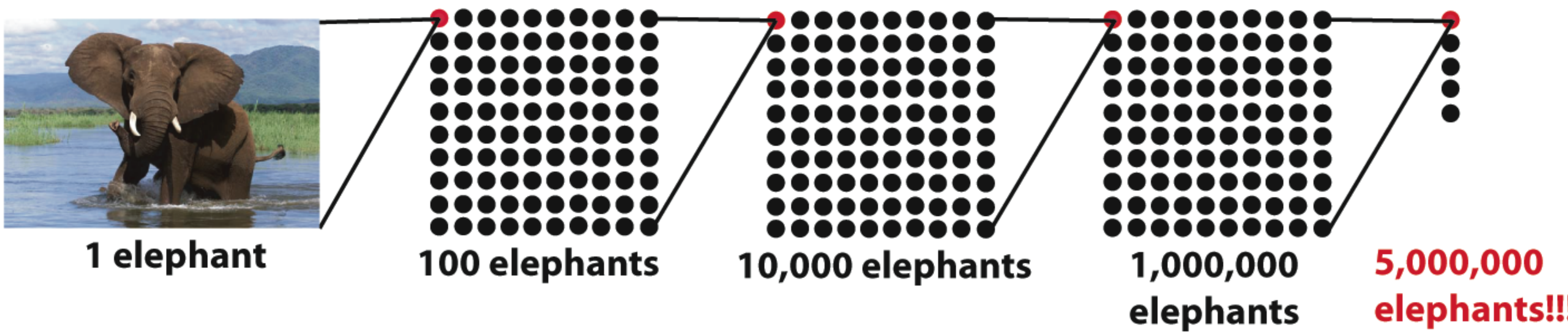
‘To appreciate this range … we represent a similar range of potential energies by contrasting the weight of a mouse with that of five elephants.’

VS

⇒ Energy is related to the square of pressure …

WRONG ANALOGY

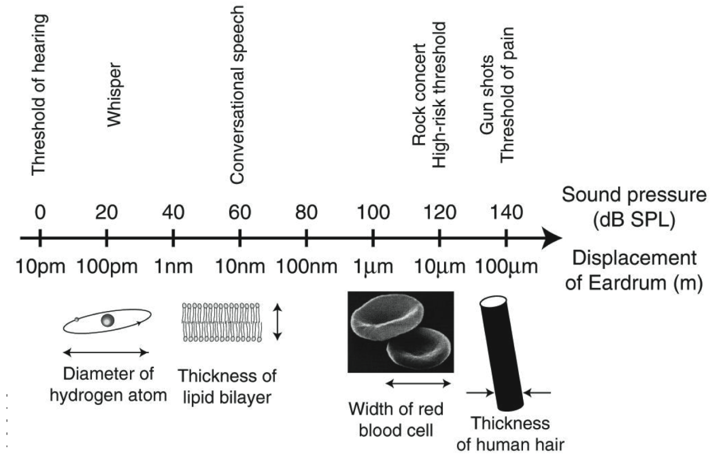
VS


1 elephant
100 elephants
10,000 elephants
1,000,000 elephants
5,000,000 elephants!!!

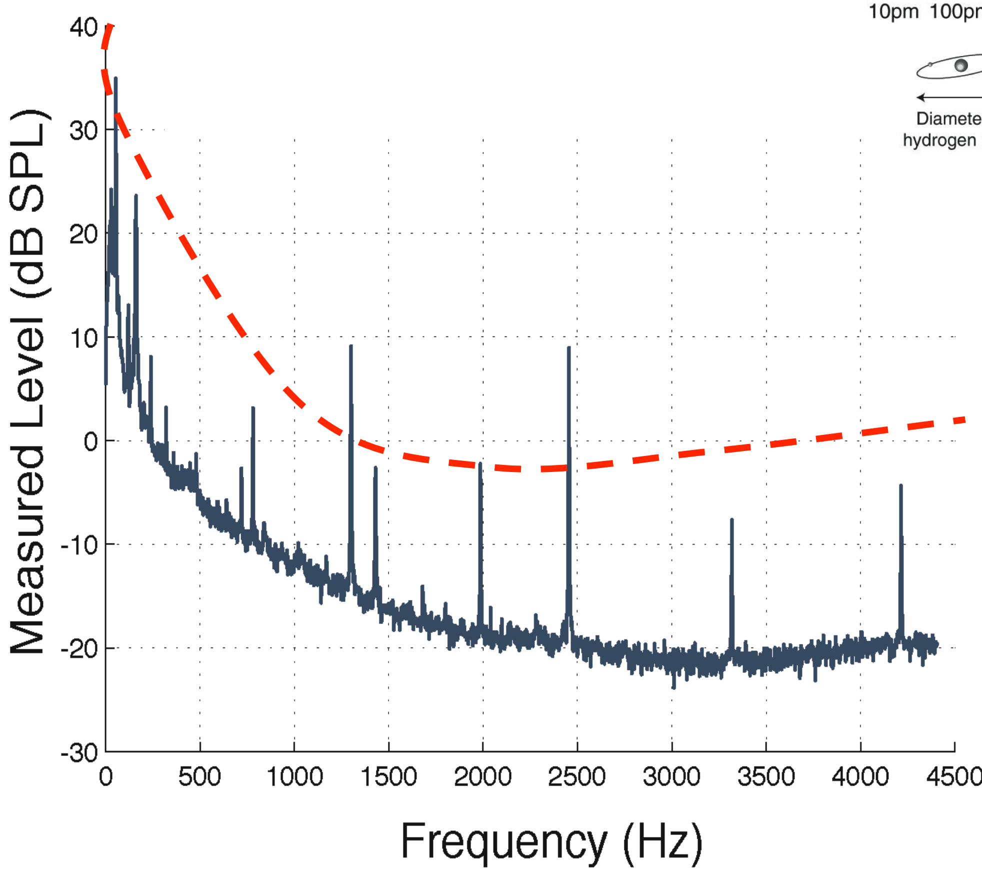
The ear actually **EMITS** sound!
(otoacoustic emission – OAE)

http://www6.miami.edu/UMH/CDA/UMH_Main/

OAEs & Threshold



D. Freeman



human threshold curve

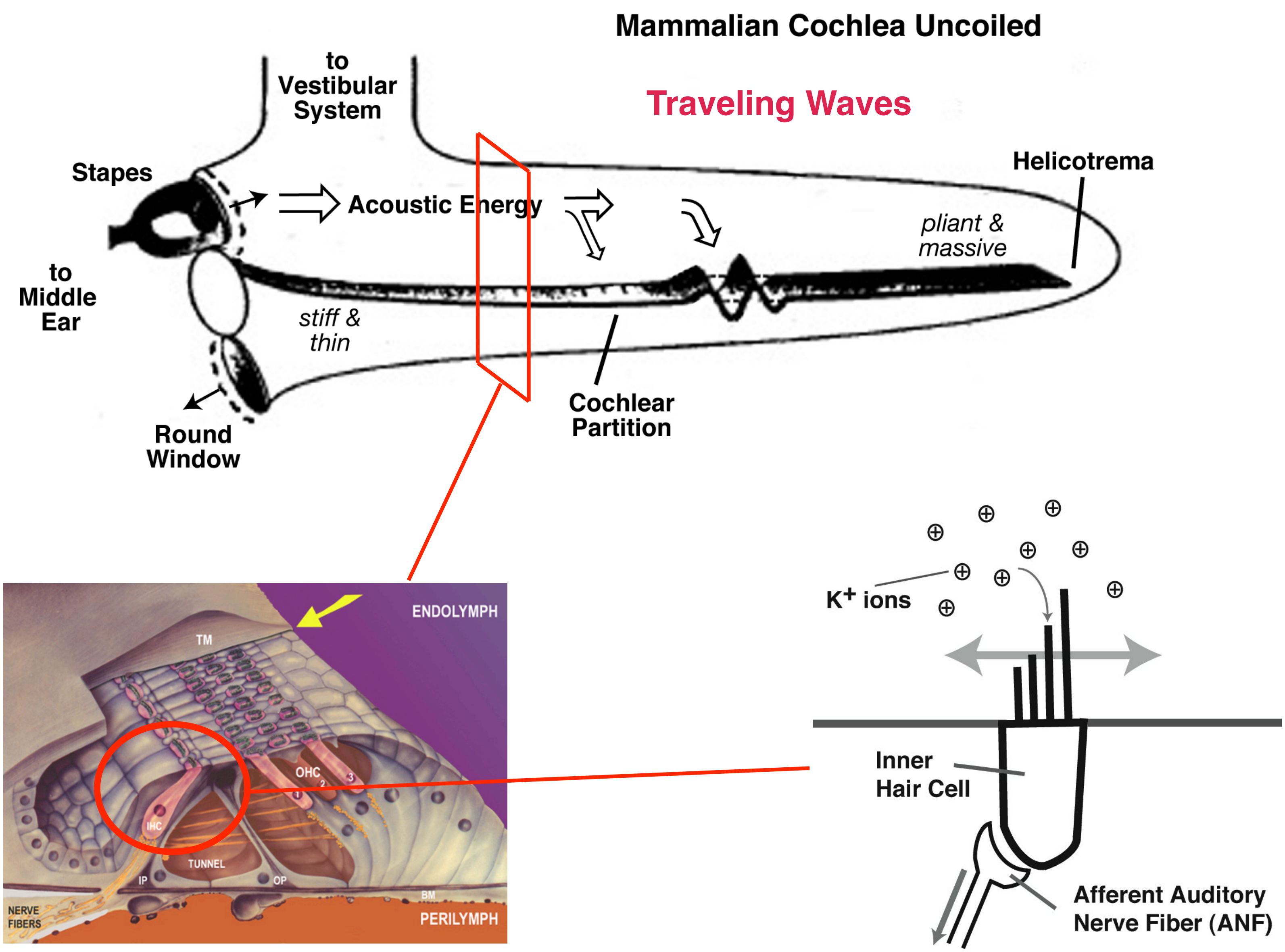
→ Spontaneous or evoked

⇒ SOAEs byproduct of an *amplification* mechanism?

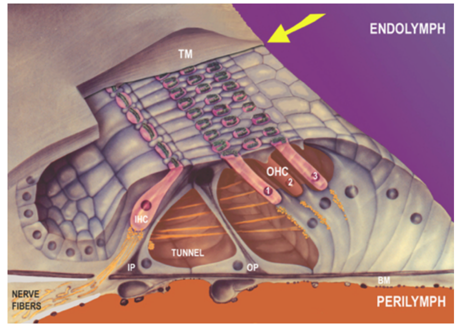
→ OAEs used for newborn hearing screening (only healthy ears emit)

→ Much faster/easier than evoked potentials (i.e., ABR)

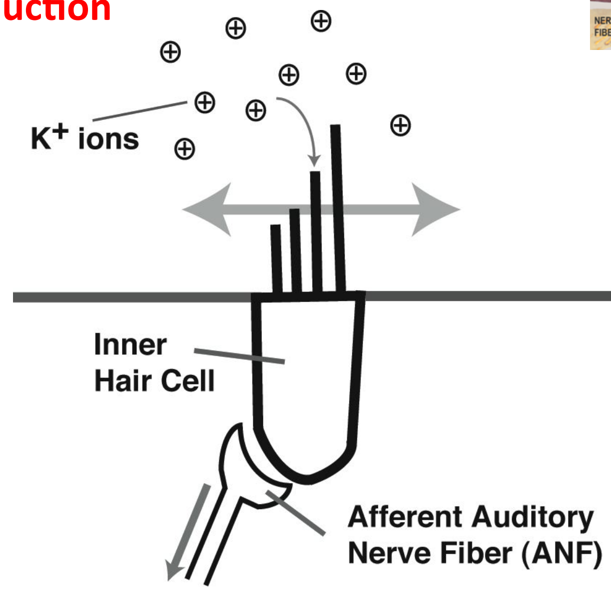
Hair Cells = Mechano-Electro Transducers



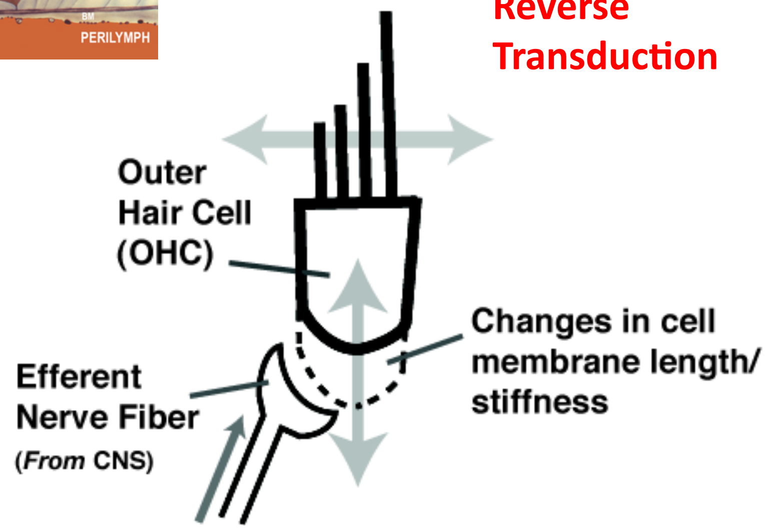
Hair cell = Amplifier?



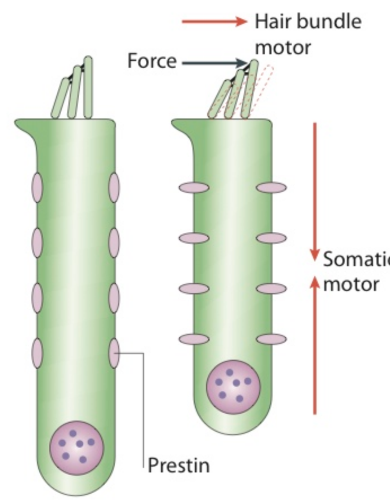
Forward Transduction



Reverse Transduction



→ Hair cells also amplify (forming basis for OAEs)



Fettiplace & Hackney (2006)