# Physics 1C

## Lecture 13A

"*Everything in the world has a spirit which is released by its sound.*"
--Oscar Fischinger

# Speed of a Wave

For example, an ocean wave is traveling in one direction has a wavelength of 1.0m and a frequency of 1.25Hz. What is the speed (in m/s) of this ocean wave?

$$v_{wave} = \lambda f = 1.25\ {}^{m}\!/_{s}$$

Please note that the water is not actually moving at this speed, but the wave is propagating at this speed.

If a cork were sitting on the water it would most likely just bob up and down.

# Clicker Question 13A-1

In the previous example, if the source of the wave suddenly doubled its frequency how would the previous answer change?

A) The velocity of the wave would quadruple.

B) The velocity of the wave would double.

C) The velocity of the wave would remain the same.

D) The velocity of the wave would half.

E) The velocity of the wave would decrease by a factor of four.

# Speed of a Wave

Let’s say I was the source of a wave, and I wanted to increase the velocity, what can I do?

Nothing, velocity is medium dependent.

I would have to change the medium.

All I can do as a source is affect the frequency, period, and amplitude of the wave.

As I change the frequency, the wavelength will change to compensate.

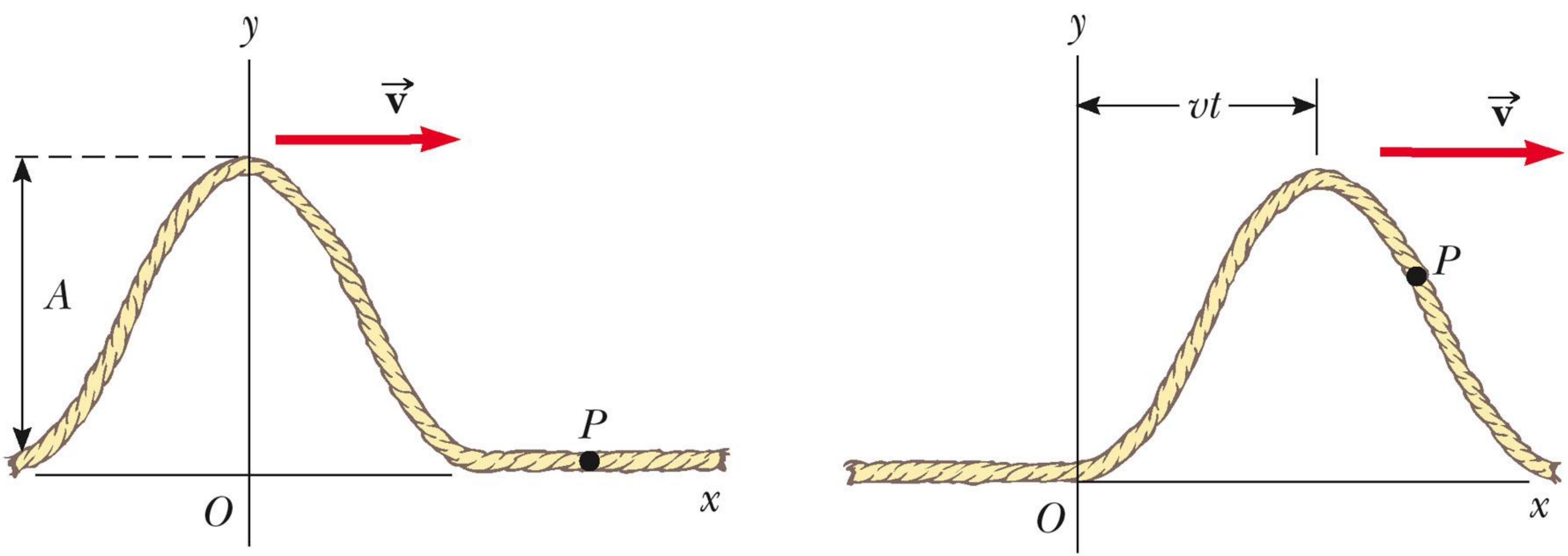
The wavelength is known as the dependent variable.

# Traveling Pulse Model

The shape of the pulse at $t = 0$ can be set by $y = f(x)$. The speed of the pulse is $v$.

For a traveling pulse: $y(x, t) = f(x \pm vt)$, depending on the direction (– to the right, + left).

$y(x, t)$ is called the **wave function**




(a) Pulse at $t = 0$

(b) Pulse at time $t$

# Traveling Wave Model

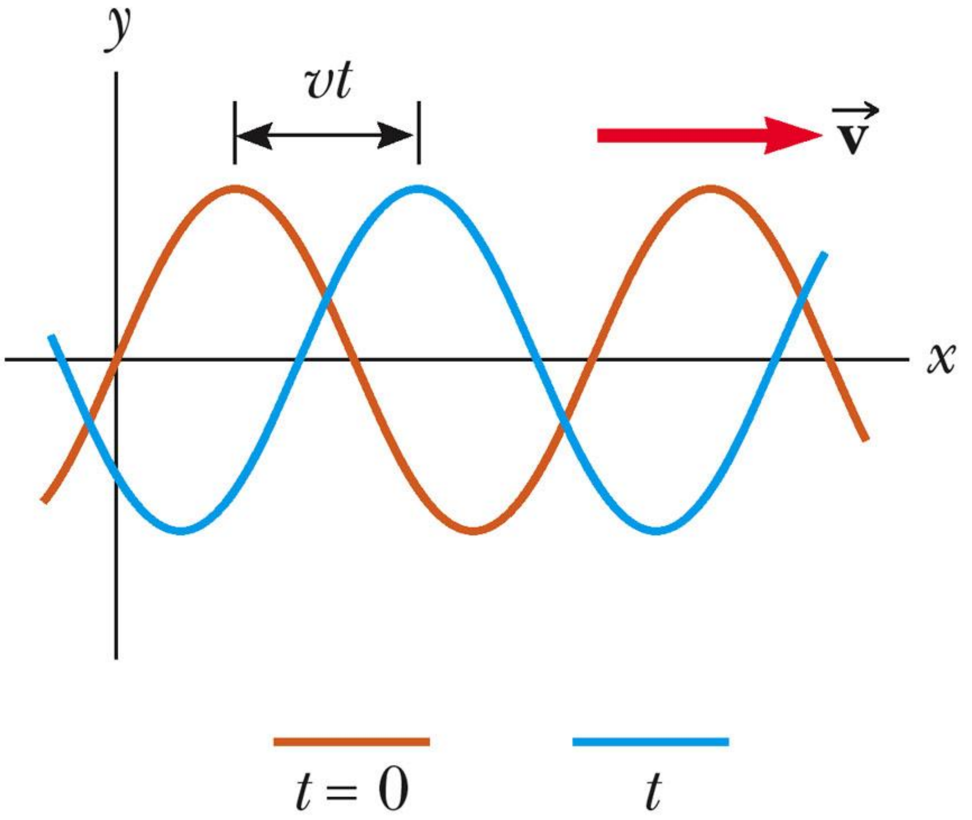
A wave snapshot at $t = 0$ is represented by the brown curve. The blue curve shows the wave at some later time $t$.

Waves travel with a specific speed, $v = \lambda / T$, that depends on the properties of the medium.

The wave function for a wave moving to the right is given by:

$$y(x,t) = A\sin\left[\frac{2\pi}{\lambda}(x - vt)\right]$$

or $$y(x,t) = A\sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right]$$



# Traveling Wave Model

The wave function $y(x, t)$ is periodic in both space and time.

We can also define angular wave number, $k$, and angular frequency, $\omega$, to write the wave function in a more compact way:

$y(x, t) = A \sin (k x - \omega t + \phi)$,

where $$k = \frac{2\pi}{\lambda}$$ and $$\omega = \frac{2\pi}{T} = 2\pi f$$

Now we can express the wave speed in alternative forms: $v = \omega/k$ and $v = \lambda/f$.

# Wave Speed on a String

Let's take the speed of the wave on a string as an example of wave speed being affected only by the medium.

How can I make the speed of the wave faster?

Make it more taut => increase the tension, $F_T$.

Make the string less dense => decrease the mass per unit length, $\mu$.

This will give us the following equation:

$$v_{string} = \sqrt{\frac{F_T}{\mu}}$$

# Clicker Question 13A-2

In the previous example, if the tension in the string were to quadruple how would the velocity change?

A) The velocity of the wave would quadruple.

B) The velocity of the wave would double.

C) The velocity of the wave would remain the same.

D) The velocity of the wave would half.

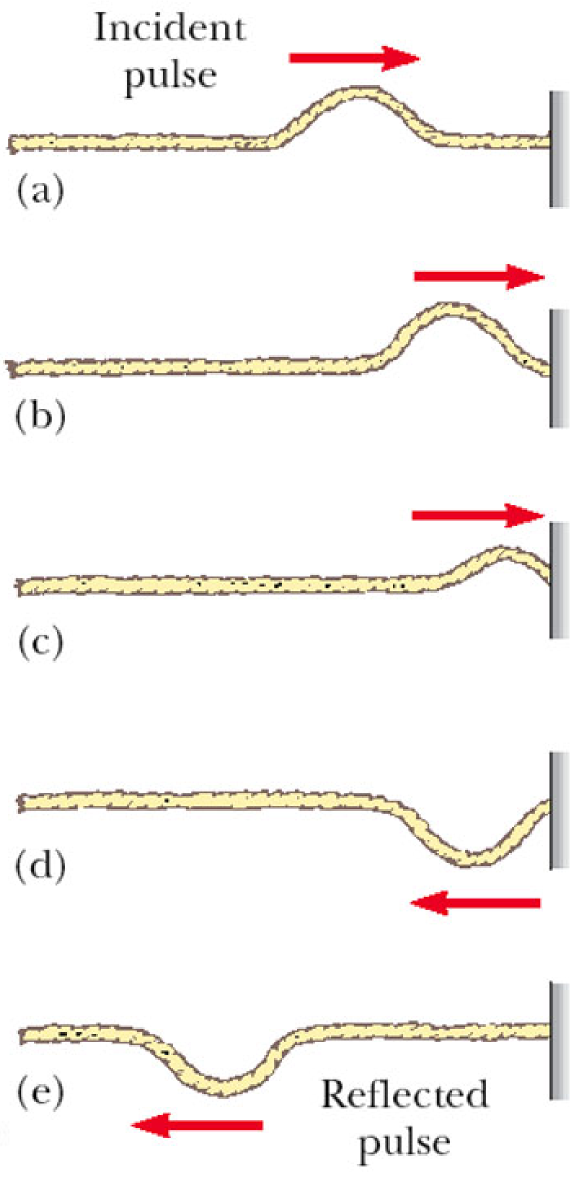
E) The velocity of the wave would decrease by a factor of four.

# Wave Reflections

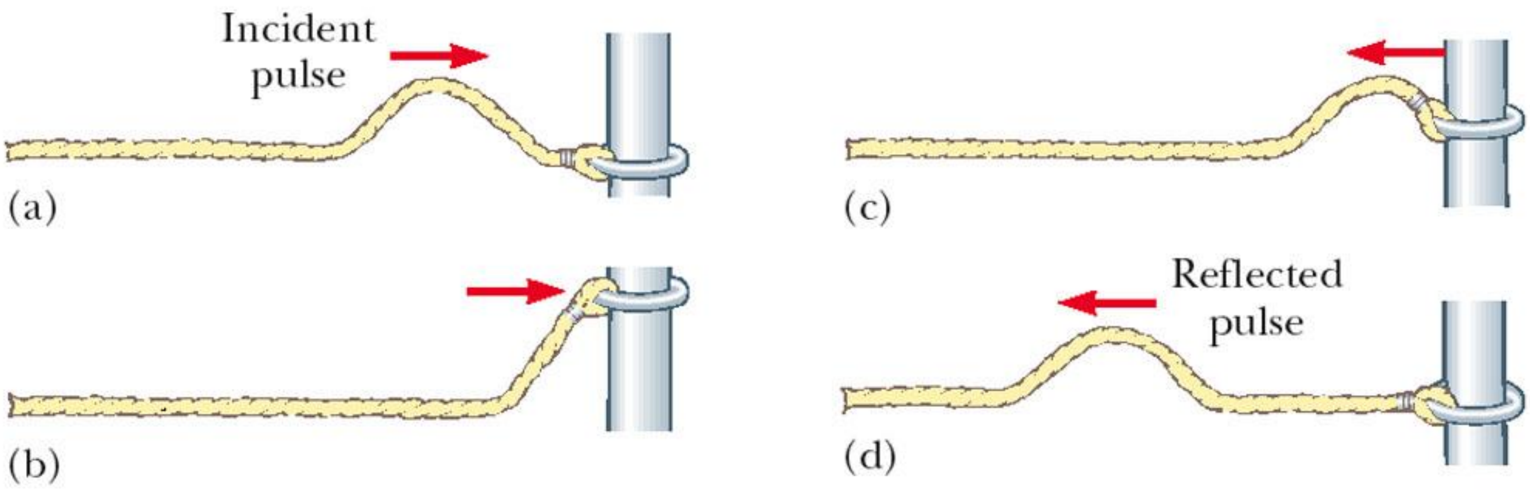
Whenever a traveling wave reaches a boundary, some or all of the wave is reflected.

When it is reflected from a fixed end, the wave is inverted.

When reflected from a free end, the pulse is not inverted.





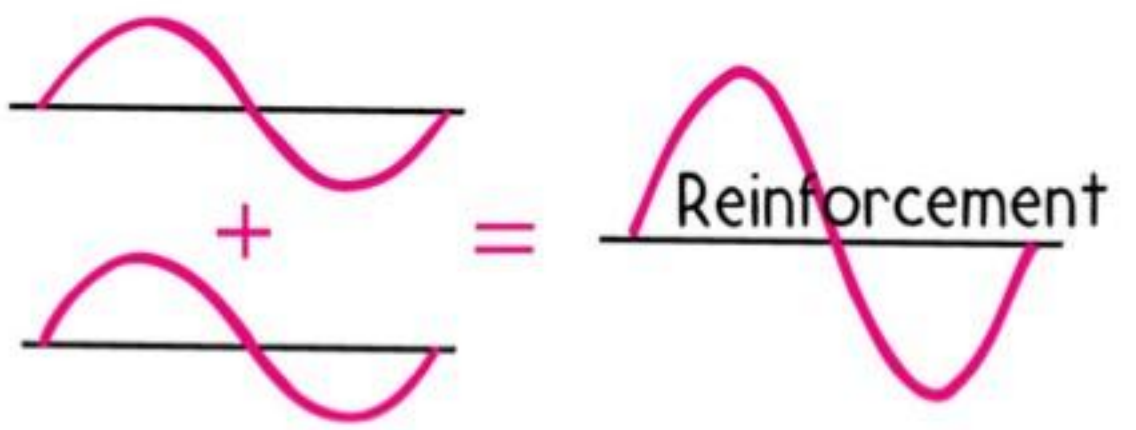
# Wave Superpositions

What happens if two waves on a string meet up and pass through each other?

They obey the **superposition principle**.

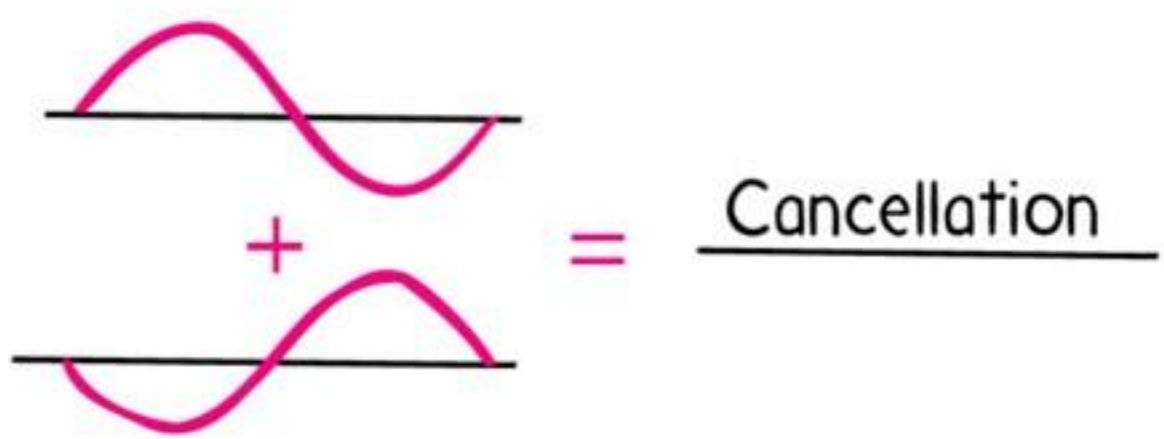
This means that you add together their individual displacements.

We can have either **constructive interference**:



# Wave Interference

Or **destructive interference**:






These traveling waves meet and pass through each other without being destroyed or even altered.

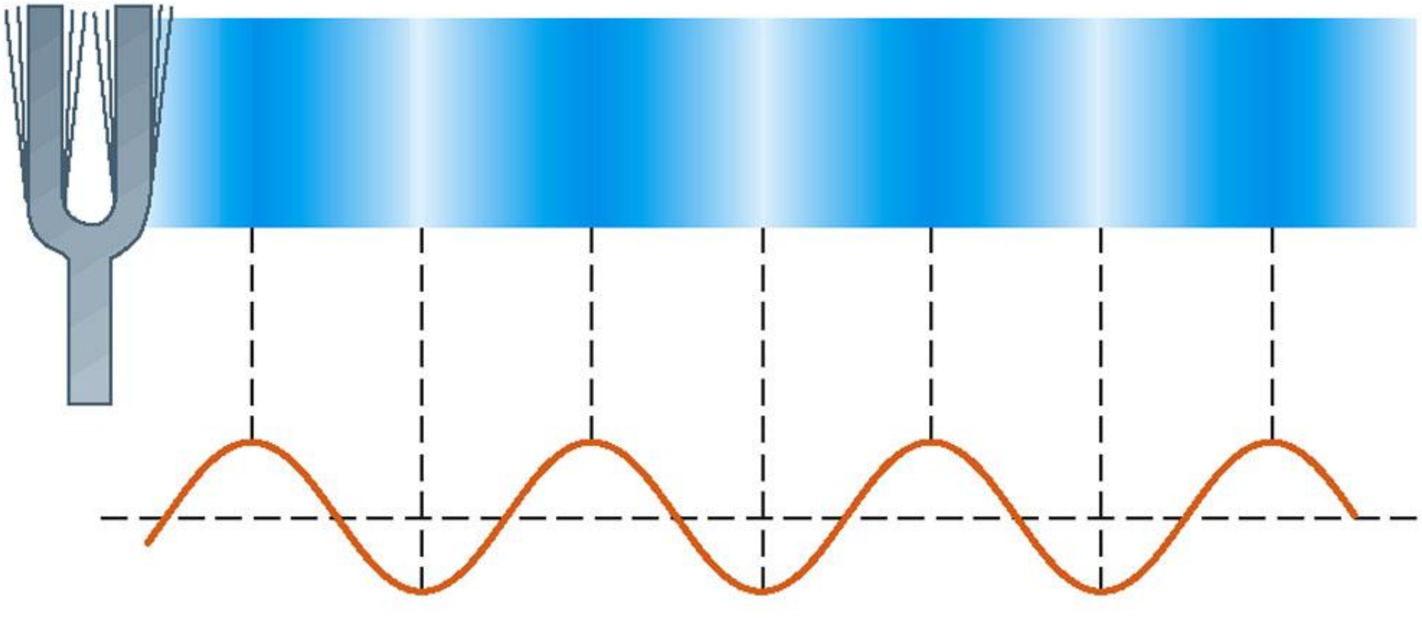
# Sound

Sound waves are longitudinal waves traveling through a medium.

<u>For all sound waves:</u>

Fluctuations in pressure/density travels through gas/liquid/solid (any medium of particles with spring-like interactions).

Source: longitudinal compression/ rarefaction of medium.



# Sound

<u>For all sound waves:</u>

Source determines period, $T$, of the sound wave.

Properties of the medium determine the speed of the sound wave, $v_{\text{wave}}$.

The wavelength, $\lambda$, will depend on the frequency, $f$, and the wave speed, $v_{\text{wave}}$.

$$v_{wave} = \frac{\lambda}{T} = \lambda f$$

Please note that the medium is not moving at this speed, but the wave is propagating at this speed.

# Sound

<u>For all sound waves:</u>

The speed of sound through a given material depends on the density of the material and how strongly the molecules in the material interact.

For a fluid that has a bulk modulus, *B*, and an equilibrium density, *ρ*, we find:

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

In general, the speed of sound through solids is greater than liquids and gases.

# Sound

At room temperature the speed of sound through air is approximately 343 m/s. The speed of sound through water is 1,490 m/s.

As the temperature of a gas (such as air) changes, so does its density and, thus, so does the speed of sound in that gas.

This leads to the following equation for the speed of sound at a given temperature:

$$v = \left(331\,{}^{\mathrm{m}}\!/\!_{\mathrm{s}}\right)\sqrt{\frac{T}{273\mathrm{K}}}$$

where 331m/s is the velocity of sound in air at 0ºC and *T* is measured in Kelvin.

# Description of a Sound Wave

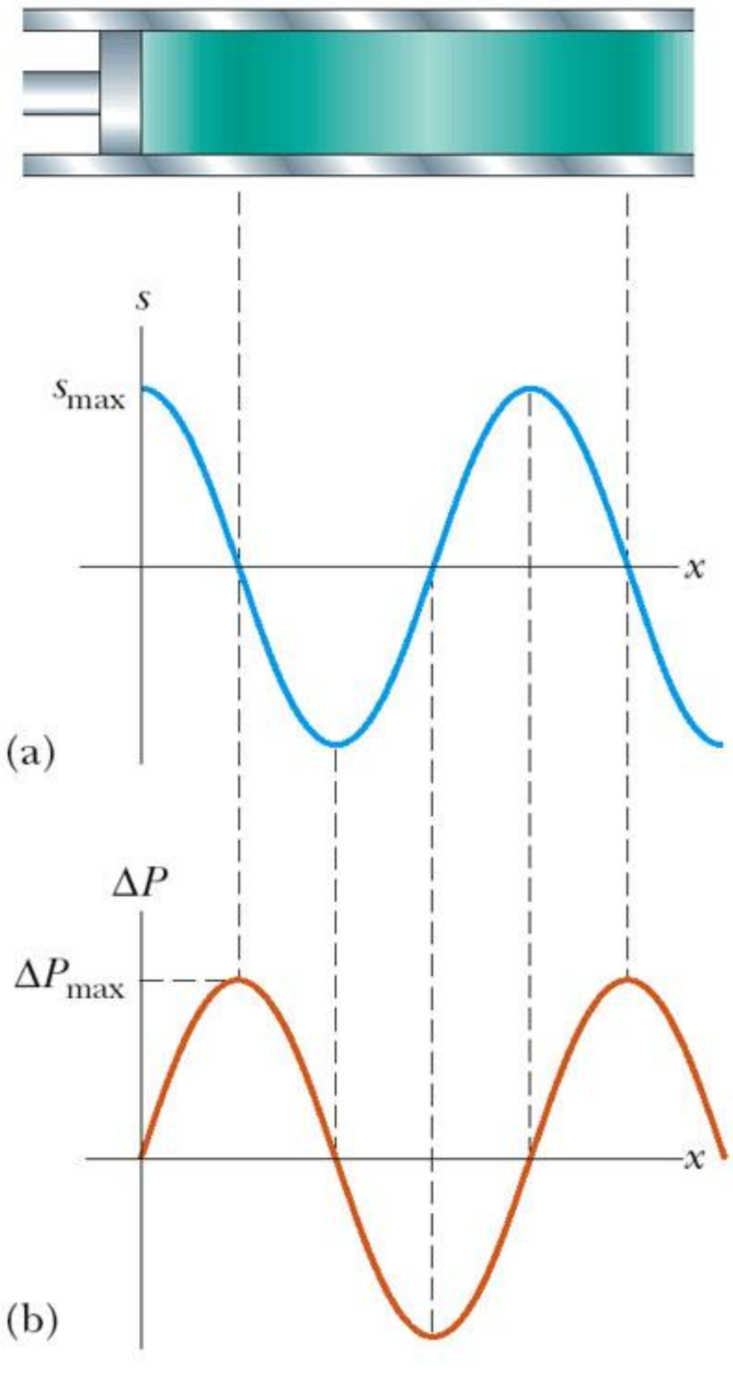
A sound wave may be considered either a **displacement wave** or a **pressure wave**

The displacement of a small element is: $s(x,t) = s_{max} \sin (kx - \omega t)$.

Here $k$ is the wavenumber, $\omega$ is the angular frequency of the piston.

The variation $\Delta P$ in the pressure of the gas about its equilibrium value is also sinusoidal:
$\Delta P = \Delta P_{max} \cos (kx - \omega t)$

The pressure wave is 90º out of phase with the displacement wave.



# Equations

$$\sum \vec{F}_{Hooke's} = -k(\Delta\vec{x}); \quad a = -\frac{k}{m}x; \quad v = \pm\sqrt{\frac{k}{m}\left(A^2 - x^2\right)}; \quad T_{mass-spring} = 2\pi\sqrt{\frac{m}{k}}; \quad T_{pend} = 2\pi\sqrt{\frac{L}{g}};$$

$$T_{physpend} = 2\pi\sqrt{\frac{I}{mgd}}; \quad f = \frac{1}{T}; \quad \omega = 2\pi f = \sqrt{\frac{k}{m}}; \quad x = A\cos(\omega t + \phi) = A\cos(2\pi f t + \phi);$$

$$v = \frac{dx}{dt} = -A\omega\sin(\omega t + \phi) = -2\pi A f\sin(2\pi f t + \phi);$$

$$a = \frac{d^2x}{dt^2} = -A\omega^2\cos(\omega t + \phi) = -(2\pi f)^2 A\cos(2\pi f t + \phi); \quad U_{grav} = mgh;$$

$$K = \tfrac{1}{2}mv^2 = \tfrac{1}{2}mA^2\omega^2\sin^2(\omega t + \phi); \quad U_{spring} = \tfrac{1}{2}k(\Delta x)^2 = \tfrac{1}{2}kA^2\cos^2(\omega t + \phi); \quad W = \left|\vec{F}\right|\left|\Delta\vec{x}\right|\cos\theta;$$

$$W_{\mathrm{nc}} = \Delta E_{mec}; \quad E_{mec} = K + U_{grav} + U_{spring}; \quad E_{SHM} = \frac{1}{2}kA^2; \quad A_{circle} = \pi r^2; \quad A_{sphere} = 4\pi r^2;$$

# For Next Time (FNT)

Study for Quiz 1

Quiz will cover chapters 12 and 13

Chapter 13 homework.

Next time Doppler effect and mathematical description of wave interference.