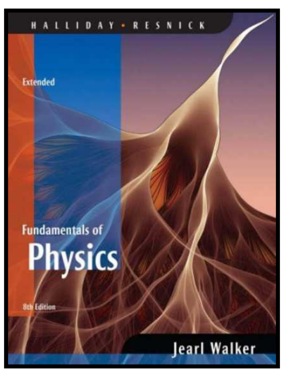
Workshop Physics 1017 - 312

University Physics II

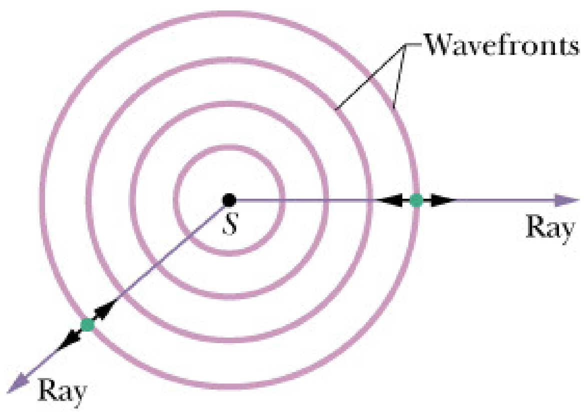


Week 7 : Day 2

Outline

- What is a sound wave?
- Traveling sound waves
  - Displacement waves
  - Speed of sound waves
- Pressure waves
  - Sound intensity and sound level
  - The decibel measure

What is a sound wave?



Sound waves are mechanical **longitudinal** waves that propagate in solids, liquids, and gases.

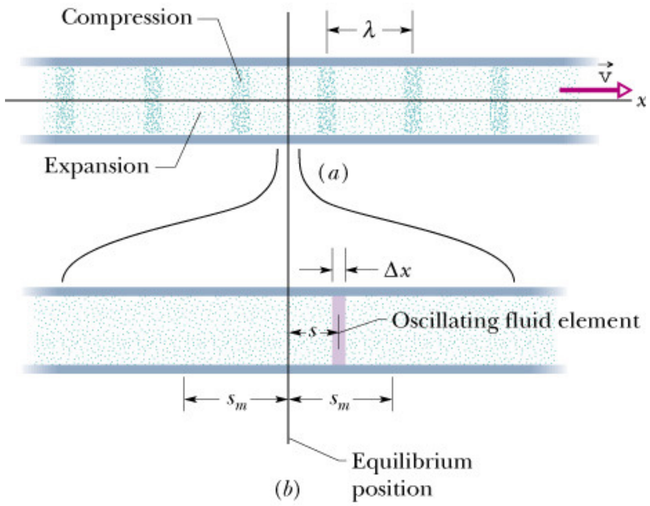
Points of a sound wave that have the same displacement are called "**wavefronts.**"

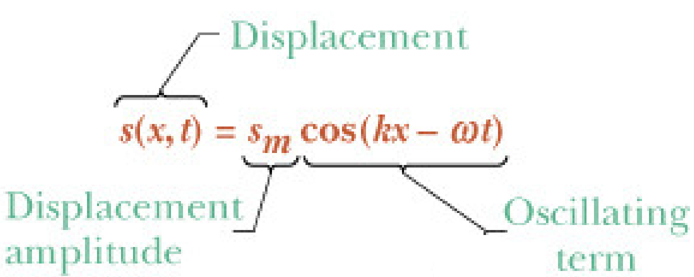
Lines perpendicular to the wavefronts are called "**rays**" and point along the direction the sound wave propagates.

For a point source of sound (shown in figure) if we assume that the surrounding medium is isotropic, then the sound propagates with the same speed in all directions. Therefore the wavefronts are spheres centered at the point source.

Examples of sound waves include:
Seismic waves used by oil explorers propagate in the Earth's crust.
Sound waves generated by a sonar system propagate in the sea.
An orchestra creates sound waves that propagate in the air.

Traveling Sound Waves

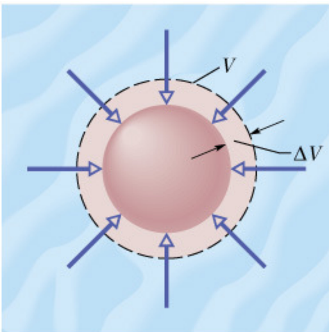




The sound wave in the tube can be described using one of two parameters:

One such parameter is the distance $s(x,t)$ of the element from its equilibrium position $s(x,t) = s_m \cos(kx - \omega t)$. The constant s_m is the **displacement amplitude** of the wave. The angular wavenumber k and the angular frequency ω have the same meaning as in the case of the transverse waves studied in Chapter 16.

The Speed of Sound



The bulk modulus of the compressed material is defined as $B = -\frac{\Delta p}{\Delta V / V}$, SI unit: the Pascal.

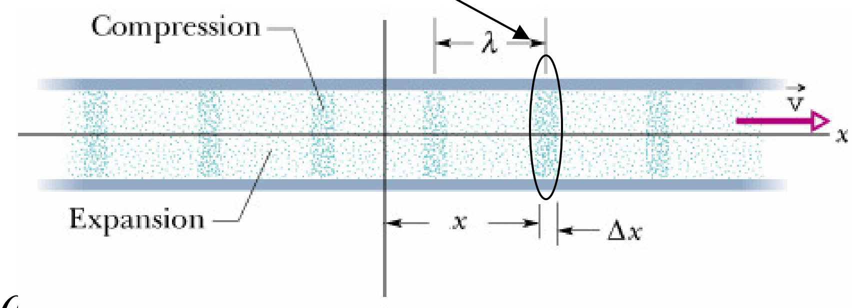
Note: The negative sign denotes the **decrease** in volume when Δp is positive.

Using the above definition of the bulk modulus and combining it with Newton's second law, one can show that the speed of sound in a homogeneous isotropic medium with bulk modulus B and density ρ is given by the equation $v = \sqrt{\frac{B}{\rho}}$.

Derivation of Speed of Sound

❑ From Newton's Law

Mass element, dm moves with speed v …



Pressure from element exerts force backward – tending to slow the wave…

$$dF = dma = (\rho A v dt)\frac{dv}{dt}$$

$$\Rightarrow \frac{dF}{A} = \rho v dv = \rho v^2 \frac{dv}{v}$$

$$\Rightarrow dp = -\rho v^2 \frac{dv}{v} = -\rho v^2 \frac{dV}{V}$$

$$\Rightarrow dm = \rho A v dt$$

$$V = Adx = Avdt$$

$$\Rightarrow \frac{d}{dv}V = Adt = \frac{Avdt}{v} = \frac{V}{v}$$

❑ From Ideal Gas Law

A constant pressure element is defined to be the *Bulk Modulus* for a given medium…

$$pV = nRT$$

$$\Rightarrow \frac{dp}{dV} = \frac{d}{dV}\frac{nRT}{V} = -\frac{nRT}{V^2} = -\frac{p}{V}$$

$$\Rightarrow dp \equiv -B\frac{dV}{V}$$

Comparing results gives the speed…

$$B \equiv \rho v^2$$

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

Speed of Sound Dependence

- **Depends on the material medium**
  - Density of materials a factor
    - *Density of water 1000 times density of air*
- **Depends on the temperature**
  - For air dependence is given by the following formula:

$$v_{sound\ \ in\ \ air} \approx 331.4 + 0.6T_C \ \ m/s$$

  - Examples: (air)
    - *20 C° = 68 F° → 343.6 m/s = 769.7 mph*
    - *-10 F° = -23.3 C° → 317.2 m/s = 710.5 mph*
  - For ideal gases use:

$$v_{sound} = \sqrt{\frac{\gamma RT}{M}}$$

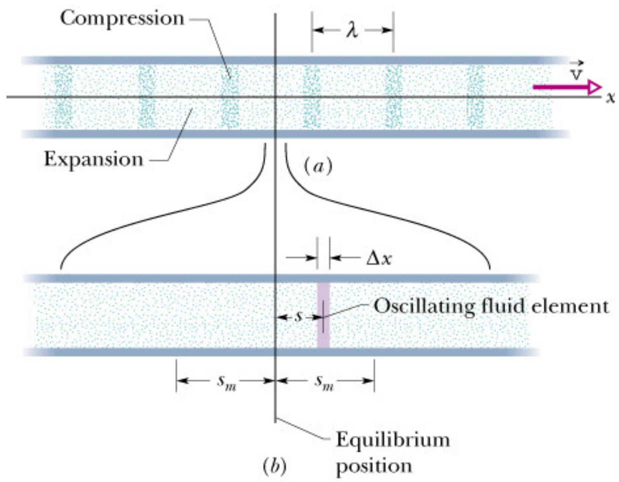
where
γ = adiabatic constant
R = gas constant
M = molecular mass of gas
T = absolute temperature

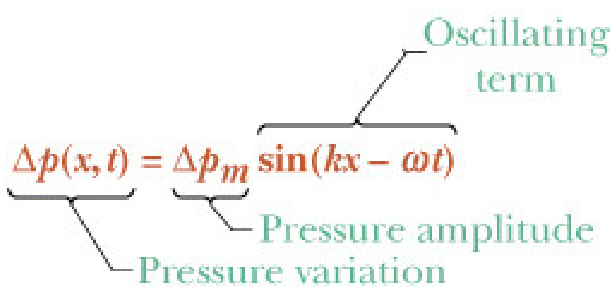
Medium	Velocity (m/s)
Air	**331**
Water	**1402**
Aluminum	**6420**

Celsius to Fahrenheit Conversion

$$T_C = \frac{5}{9}\left(T_F - 32^\circ\right)$$

Pressure waves





The second possibility is to use the pressure variation Δp from the static value: $\Delta p(x,t) = \Delta p_m \sin(kx - \omega t)$.

The constant Δp_m is the wave's pressure **amplitude.**

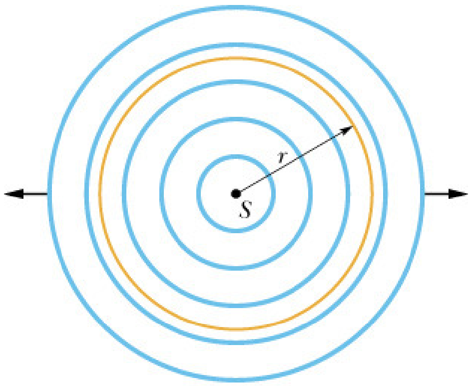
$$1atm = 101325Pa = 1.01325 \times 10^5 \frac{N}{m^2}$$

Note : The displacement and the pressure variation have a phase difference of 90°. As a result, when one parameter has a maximum the other has a minimum and vice versa.

The two amplitudes are connected by the equation

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

Intensity of a Sound Wave



Consider a wave that is incident normally on a surface of area A. The wave transports energy. As a result power P (energy per unit time) passes through A. We define the wave intensity I as the ratio P/A:

$$I = \frac{P}{A} \qquad \text{SI units: W/m}^2$$

The intensity of a harmonic wave with displacement amplitude s_m is given by

$$I = \left(\frac{\rho v \omega^2}{2}\right) s_m^2.$$ In terms of the pressure amplitude, $$I = \left(\frac{1}{2\rho v}\right)\Delta p_m^2.$$

Consider a point source S emitting a power P in the form of sound waves of a particular frequency. The surrounding medium is isotropic so the waves spread uniformly. The corresponding wavefronts are spheres that have S as their center. The sound intensity at a distance r from S is $I = \dfrac{P}{4\pi r^2}$.

The intensity of a sound wave for a point source is proportional to $\dfrac{1}{r^2}$.

The decibel measure

The auditory sensation in humans is proportional to the logarithm of the sound intensity I. This allows the ear to perceive a wide range of sound intensities. The threshold of hearing I_0 is defined as the lowest sound intensity that can be detected by the human ear: $I_0 = 10^{-12}$ W/m^2. The sound level β is defined in such a way as to mimic the response of the human ear: $\beta = 10\log\left(\frac{I}{I_o}\right)$. β is expressed in decibels (dB).

We can invert the equation above and express I in terms of β as $I = I_0 \times 10^{(\beta/10)}$.

Note 1: For $I = I_0$ we have $\beta = 10\log 1 = 0$.

Note 2: β increases by 10 decibels every time I increases by a factor of 10. For example, $\beta = 40$ dB corresponds to $I = 10^4 I_0$.

Activity – comparing waves

- **Compare waves**
  - Transverse vs. longitudinal waves
- **Sound Intensity**
  - Decibel scale
- **Interference**
  - Next class!

Your Name (**Print**): ____________________ Date: ________
Group Members: ____________________
____________________ Group: ________

Comparing Waves in Strings and Sound Waves

So far we have discussed mostly waves in a string. The wave is a function of time and a single position variable, x. Next we will look at sound waves that are a function of time and the three position variables, (x, y, z). You can predict several features of sound based on the features of waves in a string. Use the text where needed.

For waves on a string moving along x-axis $y(x,t)$	For sound waves moving along x-axis $s(x, y, z, t)$
String is characterized by linear density μ with units of …	Air is characterized by … with units of …
Wave is (Transverse Longitudinal)	Wave is (Transverse Longitudinal)
Amplitude measures the change in the variable …	Amplitude measures the change in the variable …
For sinusoidal waves, in terms of the angular frequency ω and wavenumber k, the speed is	For sinusoidal waves, in terms of angular frequency ω and wavenumber k, the speed is
The speed of a string wave is determined by (source, medium, both, neither)	The speed of sound is determined by (source, medium, both, neither)
The frequency of a string wave is determined by (source, medium, both, neither)	The frequency of a sound wave is determined by (source, medium, both, neither)
The wavelength of a string wave is determined by (source, medium, both, neither)	The wavelength of a sound wave is determined by (source, medium, both, neither)
An expression for a wave moving to the left is	An expression for a wave moving to the left is
For a string characterized by μ and tension F_T, the speed is …	For air the speed is …
Waves in string carry power having units of …	Sound waves have intensity in units of …
The relation between power, amplitude, and angular frequency is…	The relation between intensity amplitude, and angular frequency is…
We can have pulses, interference, and standing waves for waves in a string.	For sound, we can have …