Physics 101H

General Physics 1 – Honors

Lecture 45 – 11/30/22

Sound

Summary

Topics

Monday: Superposition [chapter 16]

- Superposition
- Standing waves
- Boundary conditions

Today: Sound [chapter 17]

- Sound
- Intensity
- Sound perception

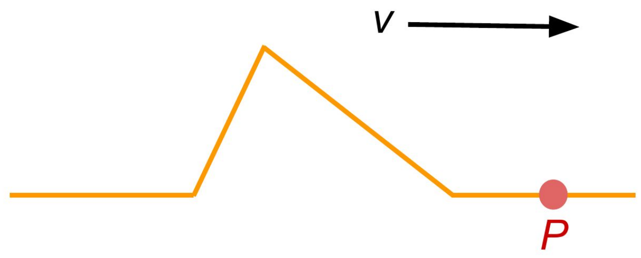
Announcements

Today:	**Problem Set 9 posted [LAST ONE!]**
Wednesday December 7:	**Problem Set 9 due**

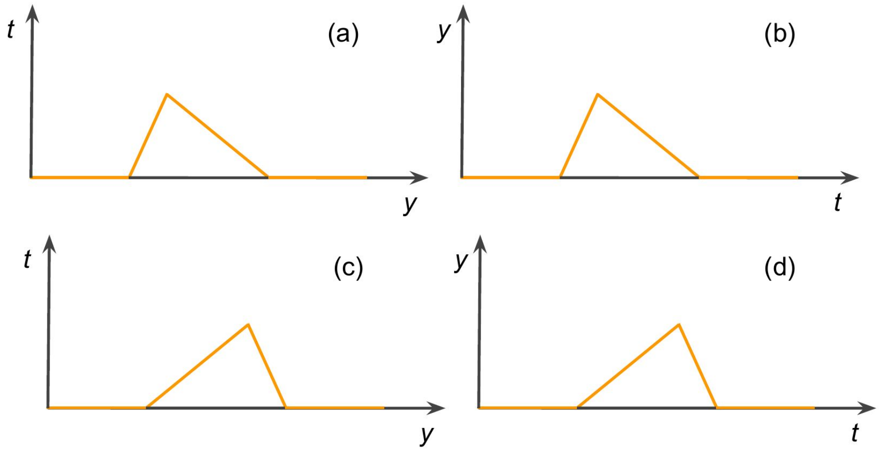
Think-pair-share

Instructions: Consider the following question. After you have had a chance to think, I will ask you to raise your hands to indicate your answer. We will then discuss with our neighbours, before voting again.

Question: A wave pulse is moving with uniform speed along a rope, shown on the right:



Which of the graphs below shows the relation between the displacement of point P and time t?



Sound

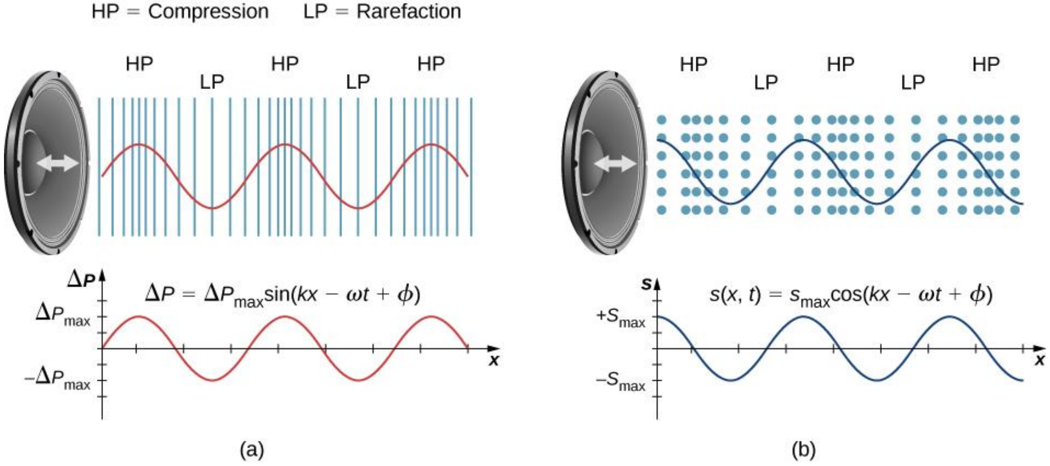
Sound is the disturbance of matter transmitted from a source outward – AKA a wave!

In fluids and gases, sound is a **longitudinal** wave

- molecules are alternatively compressed together and squeezed apart
- compressed regions are **high pressure**, while rarified regions are **low pressure**
- pressure varies sinusoidally in space and time

Solids support both longitudinal and transverse waves

Sound


HP = Compression LP = Rarefaction
HP
LP
HP
LP
HP
ΔP
$\Delta P = \Delta P_{max}\sin(kx - \omega t + \phi)$
ΔP_{max}
$-\Delta P_{max}$
x
(a)
HP
LP
HP
LP
HP
s
$s(x, t) = s_{max}\cos(kx - \omega t + \phi)$
$+S_{max}$
$-S_{max}$
x
(b)

Speed of sound

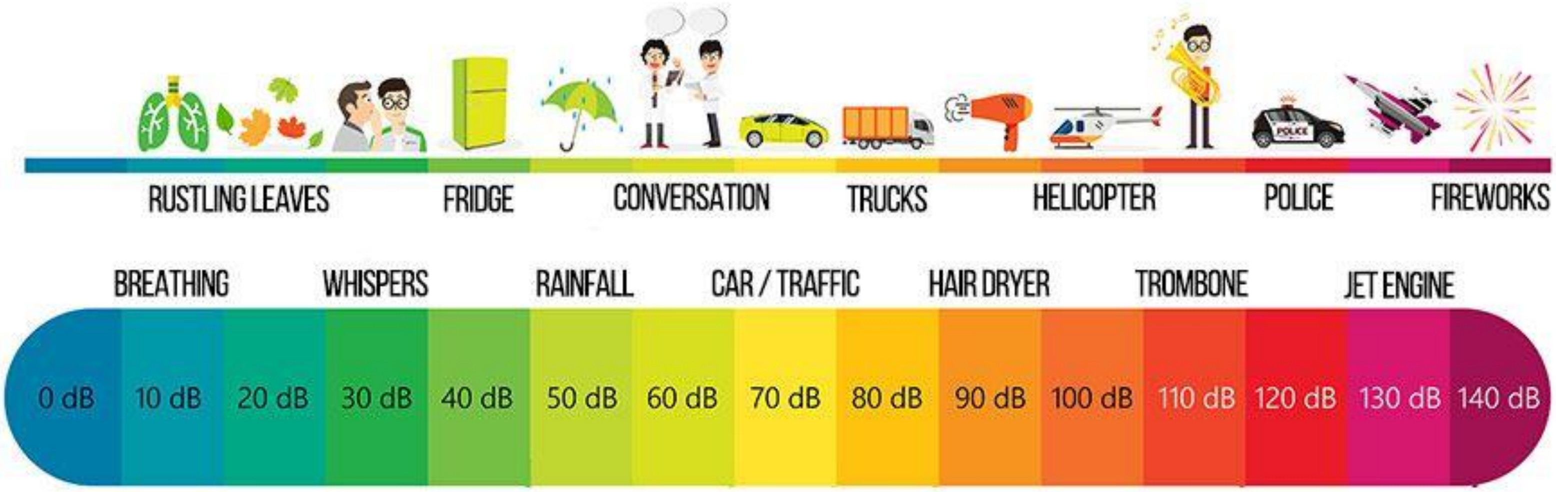
Speed of string waves depends on elastic and inertial properties of the string

Speed of sound also depends on elastic and inertial properties of the medium

Intensity and sound perception

The effect of sound (the sound effects?!) can be captured by the **intensity**

Humans are sensitive to a very wide range of intensities



Example: **(a)** Calculate the change in decibels when the sound intensity doubles.

(b) Find the difference in intensities between fireworks (140 dB) and breathing (10 dB)

Summary

Topics

Today: Sound [chapter 17]

- Sound
- Intensity
- Sound perception

Tomorrow: Doppler effect [chapter 17]

- Beats
- Standing sound waves
- Doppler effect

Announcements

Today:	**Problem Set 9 posted [LAST ONE!]**
Wednesday December 6:	**Problem Set 9 due**

NEXT WEEK:
ALL PROBLEM SETS DUE ON WEDNESDAY DECEMBER 7

PHYSICS 101 - HONORS

Lecture 45 11/30/22

Sound (slide 5)

We describe sound in terms of the pressure variations

$$P(x,t) = P_{max} \sin(kx - \omega t)$$

or in terms of the displacement of molecules from equilibrium

$$s(x,t) = s_{max} \cos(kx - \omega t)$$

← 90° out of phase
molecules are <u>not</u> displaced at the centre of high + low pressure area

Speed of sound (slide 6)

String waves $v = \sqrt{\dfrac{T}{\mu}}$ ← elastic property of the string (T); ← inertial property of the string (μ)

An analogous relation holds for sound waves

$$\boxed{v = \sqrt{\dfrac{B}{\rho}}}$$

← bulk modulus (units N/m^2 because $B = P/(\Delta V/V)$)

← density (units kg/m^3)

↑ in a fluid

← units are $\sqrt{\dfrac{kg\, m/s^2}{m^2} \Big/ kg/m^3} = \sqrt{\dfrac{m^2}{s^2}}$ ✓

In a solid, we can also have stretching

$$v = \sqrt{\frac{Y}{\rho}} \leftarrow \text{Young's modulus}$$

And in an ideal gas

$$V = \sqrt{\frac{\gamma R T_K}{M}}$$

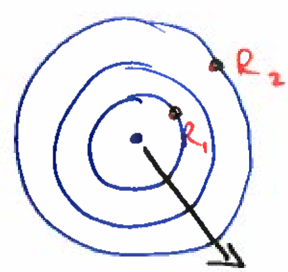
γ = adiabatic index
R = ideal gas constant = 8.31 J/mol K
T_K = temperature
M = molecular mass

Intensity (slide 7)

Intensity defined as $\boxed{I = \frac{P}{A}}$ ← power ← area ← units W/m^2

For a sound wave moving out from a point source ← a spherical wave

$$\boxed{I = \frac{P}{4\pi R^2}}$$ at distance R



The ratio of the intensities at two different points is therefore

$$\frac{I_2}{I_1} = \frac{P}{4\pi R_2^2} \Big/ \frac{P}{4\pi R_1^2} = \frac{R_1^2}{R_2^2} \quad \text{or} \quad \boxed{I_2 = \frac{R_1^2}{R_2^2} I_1}$$

It turns out humans are sensitive to a very wide range of intensities, from $10^{-12}\ W/m^2$ to $1\ W/m^2$

pain threshold

$\Rightarrow$ natural to define <u>sound intensity level</u>

$$\beta = 10 \log_{10} \frac{I}{I_0}$$

units are decibels (dB) $\leftarrow$ $I_0 = 10^{-12}\ W/m^2$

Lowest intensity is I_0 at 0 dB

Highest (safe) intensity is pain threshold ~ 120 dB

Sounds at different frequencies are heard as different <u>pitches</u>, whereas intensity is perceived as <u>loudness</u>

These combine to produce the <u>timbre</u> – the quality of sound produced by different intensities of different harmonic modes

Example: decibels (slide 8)

(a) Let $I_2 = 2I_1$

$$\Rightarrow \quad \beta_2 = 10 \log_{10}\left(\frac{I_2}{I_0}\right)$$

$$\beta_1 = 10 \log_{10}\left(\frac{I_1}{I_0}\right)$$

$$\Rightarrow \Delta\beta = \beta_2 - \beta_1$$

$$= 10 \log_{10}\left(\frac{I_2}{I_0}\right) - 10 \log_{10}\left(I_1/I_0\right)$$

$$= 10\left(\log_{10}\left[\frac{I_2}{I_0} \Big/ \frac{I_1}{I_0}\right]\right)$$

$$= 10 \log_{10}\left(\frac{I_2}{I_0}\,\frac{I_0}{I_1}\right)$$

$$= 10 \log_{10}\left(\frac{I_2}{I_1}\right)$$

$$= 10 \underbrace{\log_{10}(2)}_{= 0.3}$$

$$= \underline{3\text{ dB}}$$

(b) $\beta_2 = 140\ dB$

$\beta_1 = 10\ dB$

$\beta_2 - \beta_1 = 130$

We just saw that $\Delta\beta = \beta_2 - \beta_1$ is given by

$$\Delta\beta = 10 \log_{10}\left(\frac{I_2}{I_1}\right)$$

$$\Rightarrow \log_{10}\left(\frac{I_2}{I_1}\right) = \frac{\Delta\beta}{10}$$

or $$\frac{I_2}{I_1} = 10^{\left(\frac{\Delta\beta}{10}\right)}$$

$$= 10^{\frac{130}{10}}$$

$$= \underline{10^{13}} \qquad (!!)$$