

Physics 1408-002 Principles of Physics

Lecture 26
– Chapter 16 –
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Announcement I

Lecture note is on the web

Handout (6 slides/page)

<http://highenergy.phys.ttu.edu/~slee/1408/>

*** Class attendance is strongly encouraged and will be taken randomly. Also it will be used for extra credits.

HW Assignment #10 (Ch. 14,15,16) is placed on MateringPHYSICS, and is due by 11:59pm on Wednesday, 4/29

Announcements II

**Final Exam
(All Chapters)
4/30 Thursday @ Sci 7**

**7:30 am – 10:00 am
2.5 hours**

Exams - Overview

- The exams are closed book. You may bring **one hand-written 3" x 5" index card** with formulae, etc. Telephones, iPod and other gizmos are not allowed. Small **calculators are allowed**.
- The final exam is **comprehensive (3~5 min problems)** and is a common exam for all sections (~Total 20~25 problems: i.e. 1~2 / chapter) – YES, it's a **multiple choice** exam!!
- Please bring a **scantron sheet (orange)** for the exam!!

Announcement III

**SI session by
Reginald Tuvilla**

**Next week, final exam review will be on
Monday 04/06 from 4:30 - 7:30.
(Room: HH 28)**

Chapter 16 Sounds



- Characteristics of Sound
- Mathematical Representation of Longitudinal Waves
- Intensity of Sound: Decibels
- Sources of Sound: Vibrating Strings and Air Columns
- Quality of Sound, and Noise; Superposition
- Interference of Sound Waves; Beats
- Doppler Effect & Shock Waves and the Sonic Boom

16-1 Characteristics of Sound

Sound can travel through any kind of matter, but not through a vacuum.

TABLE 16-1 Speed of Sound in Various Materials (20°C and 1 atm)

Material	Speed (m/s)
Air	343
Air (0°C)	331
Helium	1005
Hydrogen	1300
Water	1480
Sea water	1500
Iron and steel	~5000
Glass	~5000
Aluminum	~5100
Hardwood	~4000
Concrete	~3000

The speed of sound is different in different materials;

in general, it is slowest in gases, faster in liquids, and fastest in solids.

The speed depends somewhat on temperature, especially for gases.

Speed of Sound in Air

- The speed of sound also depends on the **temperature** of the medium
- This is particularly **important with gases**
- For air, the relationship between the speed and temperature is

$$v = (331 \text{ m/s}) \sqrt{1 + \frac{T_C}{273^\circ \text{C}}}$$

- The **331 m/s** is the speed at **0° C**
- T_C** is the air temperature in Celsius

16-1 Characteristics of Sound

Loudness: related to intensity of the sound wave

Pitch: related to frequency (High or low)

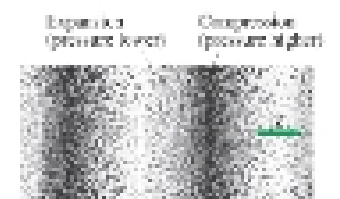
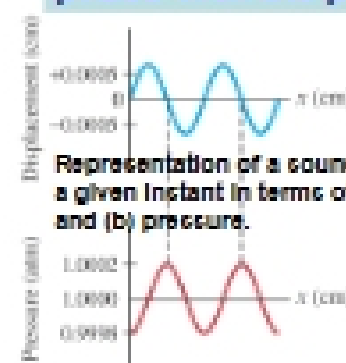
Audible range: about 20 Hz to 20,000 Hz; upper limit decreases with age

Ultrasound: above 20,000 Hz; see ultrasonic camera focusing in following example

Infrasound: below 20 Hz

16-2 Mathematical Representation of Longitudinal Waves

Longitudinal waves are often called pressure waves. The displacement is 90° out of phase with the pressure.



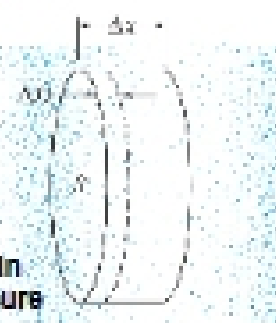
Longitudinal sound wave travelling to the right, and its graphical representation in terms of pressure

16-2 Mathematical Representation of Longitudinal Waves

By considering a small cylinder within the fluid, we see that the change in pressure is given by (*B* is the bulk modulus):

$$\Delta P = -B(\Delta V/V), \quad \Delta P = -B(S\Delta D/S\Delta x)$$

$$\Delta P = -B \frac{\partial D}{\partial x}$$



Longitudinal wave in a fluid moves to the right. A thin layer of fluid changes in volume as a result of pressure variation as the wave passes. At the moment shown, the pressure will increase as the wave moves to the right, so the thickness of our layer will decrease, by an amount Δ*D*.

16-2 Mathematical Representation of Longitudinal Waves

If the displacement is sinusoidal, we have

$$D = A \sin(kx - \omega t), \quad \Delta P = -(BAk) \cos(kx - \omega t),$$

$$\Delta P = -B \frac{\partial D}{\partial x}, \quad \Delta P = -\Delta P_{\max} \cos(kx - \omega t)$$

where, using $v = \sqrt{\frac{B}{\rho}}$, and $v = \frac{\omega}{k}$

It is also given by $\Delta P_{\max} = B A k = \rho v^2 A k$

16-3 Intensity of Sound: Decibels

TABLE 16-2
Intensity of Various Sounds

Source of the Sound	Sound Level (dB)	Intensity (W/m^2)
Jet plane at 30 m	140	100
Threshold of pain	120	1
Lead rock concert	120	1
Shower at 30 m	100	1×10^{-2}
Truck traffic	90	1×10^{-3}
Busy street traffic	80	1×10^{-4}
Noisy restaurant	70	1×10^{-5}
Talk at 30 cm	65	3×10^{-6}
Quiet radio	40	1×10^{-8}
Whisper	30	1×10^{-9}
Rattle of leaves	10	1×10^{-11}
Threshold of hearing	0	1×10^{-12}

The intensity of a wave is the energy transported per unit time across a unit area.

The human ear can detect sounds with an intensity as low as 10^{-12} W/m^2 and as high as 1 W/m^2 . [Watts/m²]

16-3 Intensity of Sound: Decibels

The loudness of a sound is much more closely related to the logarithm of the intensity.

Sound level is measured in **decibels (dB)** and is defined as:

$$\beta \text{ (in dB)} = 10 \log \frac{I}{I_0}$$

I = the intensity of the sound whose level is to be determined

I_0 (reference intensity) is taken to be the **threshold of hearing**: $I_0 = 1.0 \times 10^{-12} \text{ W/m}^2$.

Note: Threshold of pain: $I = 1.00 \text{ W/m}^2$; $\beta = 120 \text{ dB}$

Sound Level, Example

- What is the sound level that corresponds to an intensity of $2.0 \times 10^{-7} \text{ W/m}^2$?
- $\beta = 10 \log (2.0 \times 10^{-7} \text{ W/m}^2 / 1.0 \times 10^{-12} \text{ W/m}^2)$
 $= 10 \log 2.0 \times 10^5 = 53 \text{ dB}$

16-3 Intensity of Sound: Decibels

An increase in sound level of 3 dB, which is a **doubling** in intensity, is a very small change in loudness.

In open areas, the **intensity of sound** diminishes with distance:

$$I \propto \frac{1}{r^2}$$

However, in **enclosed spaces** this is complicated by **reflections**, and if sound travels through air, the higher frequencies get **absorbed**.

16-4 Sources of Sound: Vibrating Strings and Air Columns

Musical instruments produce sounds in various ways—vibrating **strings**, vibrating **membranes**, vibrating metal or wood **shapes**, vibrating **air columns**.

The vibration may be started by **plucking**, **striking**, **bowing**, or **blowing**. The vibrations are transmitted to the air and then to our ears.

16-4 Sources of Sound: Vibrating Strings and Air Columns

TABLE 16-3 Equally Tempered Chromatic Scale¹

Note	Frequency (Hz)
C	262
C [♯] or D [♭]	277
D	294
D [♯] or E [♭]	311
E	330
F	349
F [♯] or G [♭]	370
G	392
G [♯] or A [♭]	415
A	440
A [♯] or B [♭]	466
B	494
C [♯]	524

¹Only one octave is included.

This table gives frequencies for the octave beginning with middle C. The equally tempered scale is designed so that music sounds the same regardless of what key it is transposed into.