PHY250: Sound

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Sound
Characteristics
Mathematical Description
Sources of Sound
Quality of Sound, and Noise; Superposition

Sound

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- Source $\rightarrow$ vibrating object.
- Needs mater to spread.
- The energy is transferred as longitudinal waves.
- Detection $\rightarrow$ ears, microphone, etc.

Sound Speed

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change in pressure $\rightarrow$ change of volume

Sound Speed

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	1440
Sea water	1560
Iron and steel	≈ 5000
Glass	≈ 4500
Aluminum	≈ 5100
Hardwood	≈ 4000
Concrete	≈ 3000

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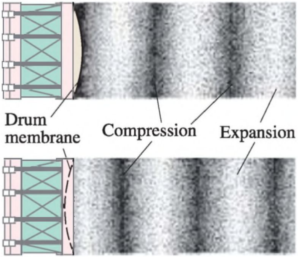

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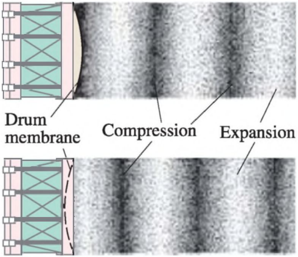
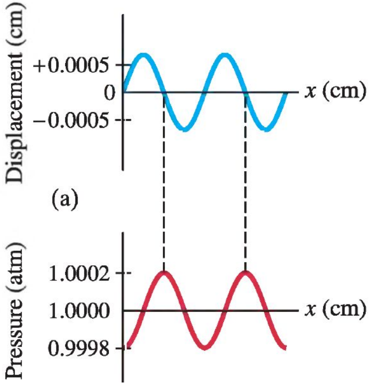


The variation of pressure is easier to measure.

Pressure Waves

The displacement and pressure are $\frac{\pi}{2}$ out of phase.



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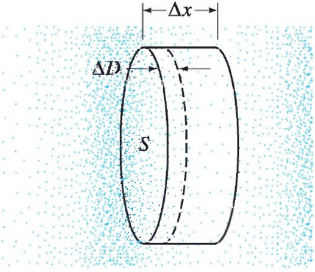

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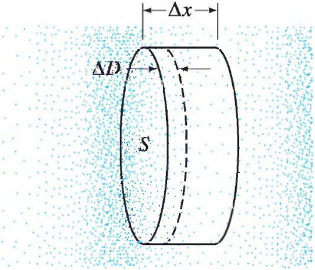

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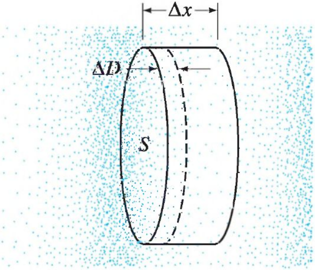

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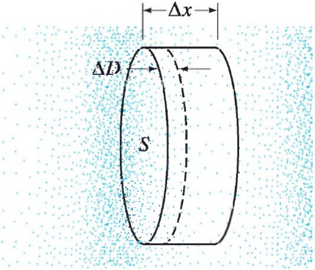

$$\Delta P = -B\frac{\Delta V}{V}$$

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$$\Delta V = S\Delta D$$

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

Pressure Waves

Taking the limit for $\Delta x \to 0$

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

$$\to \frac{\partial D}{\partial x} = kAcos(kx - \omega t)$$

$$\to \boxed{\Delta P = -BkAcos(kx - \omega t)} \quad (2)$$

The pressure amplitude is:

$$\Delta P_M = BkA \quad (3)$$

Pressure Waves

Using the relations,

$$v = \sqrt{\frac{B}{\rho}}, \;\; k = \frac{2\pi f}{v}$$

$$\Delta P_M = BkA = \boxed{2\pi v \rho f A} \tag{4}$$

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The audible range by humans is 20 Hz to 20000 Hz

Intensity of sound

We are going to define a new measurement unit that relates the intensity with loudness.

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Then, we are going to define this new unit in log scale.

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$$I_0 = 10^{-12}\ \frac{W}{m^2},\ minimum\ audible\ intensity \tag{6}$$

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At the threshold of hearing? $I = 10^{-12}\ \frac{W}{m^2}$?

$$\beta = 10 log \left(\frac{10^{-12}}{10^{-12}}\right) = 10 log 1 = 0 \tag{8}$$

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An increase in I by a factor 10^2 is equivalent to an increase in 20 dB and so on...

Decibel

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
Loud rock concert	120	1
Siren 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 50 cm	65	3×10^{-6}
Quiet radio	40	1×10^{-8}
Whisper	30	1×10^{-9}
Rustle of leaves	10	1×10^{-11}
Threshold of hearing	0	1×10^{-12}

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Conceptual example:

A trumpeter plays at a sound level of 75 dB. Three equally loud trumpet players join in. What is the new sound level?

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$$\beta = 10 log \frac{4I_1}{I_0} = 10 log(4) + 10 \ log \frac{I_1}{I_0} = 6.0 \ dB + 75 \ dB = 81 \ dB$$

Equally Tempered Chromatic Scale

PITCH $\leftrightarrow$ FREQUENCY

TABLE 16–3 Equally Tempered Chromatic Scale†

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

Sources of Sound

- VIBRATING OBJECTS

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- PUSHES THE MEDIUM

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Stringed Instruments

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v, f fixed.

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v, f fixed. ℓ variable

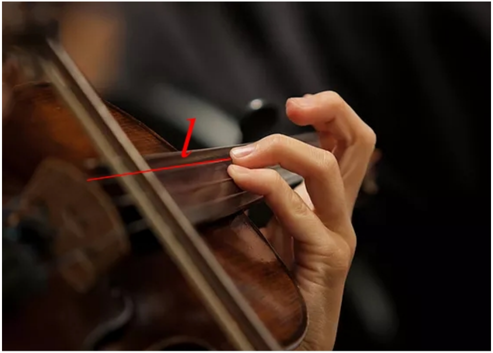

Figure from https://www.pitchperfectstrings.com.au/

Stringed Instruments

Different $\mu \rightarrow$ different pitch

Stringed Instruments

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$$v = \sqrt{\frac{F_T}{\mu}} \tag{9}$$

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The tension F_T may also be different. Adjusting the tension $\rightarrow$ tuning the pitch of each string.

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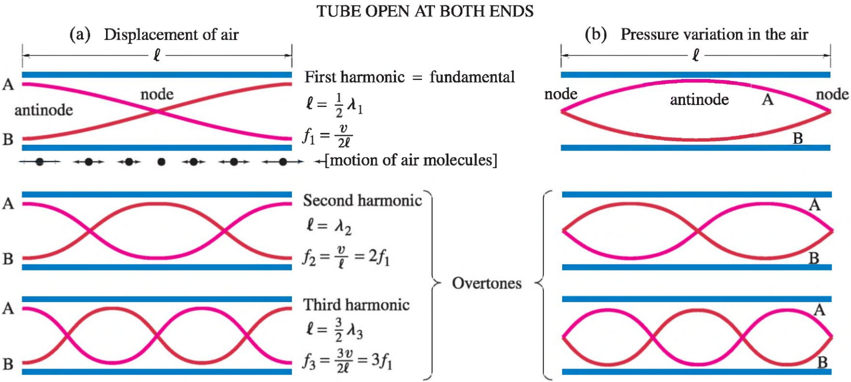
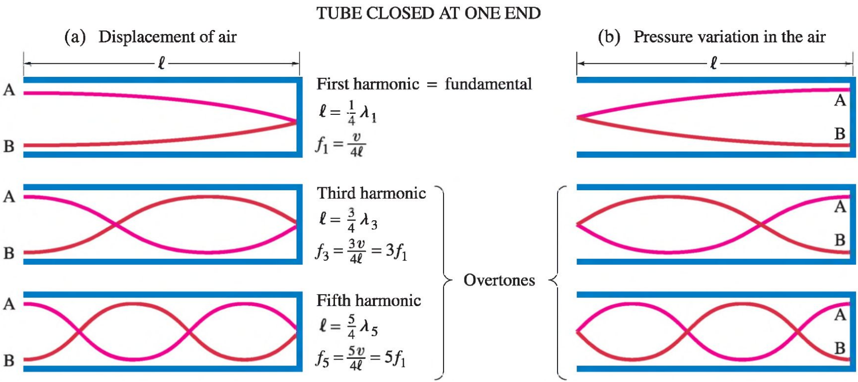
Modes of vibration for an open tube



Modes of vibration for a tube closed at one end



Quality of sound

SOUND

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$\rightarrow$ SHAPES OF THE WAVES

Quality of sound

WAVE:

$$f(t) = \sum_{n=1}^{N} A_n cos\left(\frac{2n\pi t}{L}\right)$$

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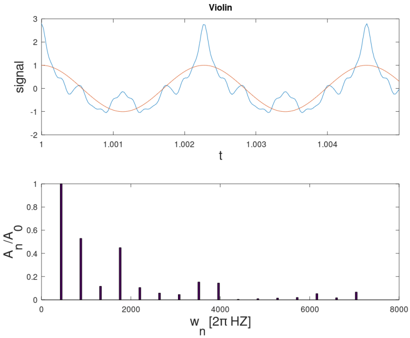
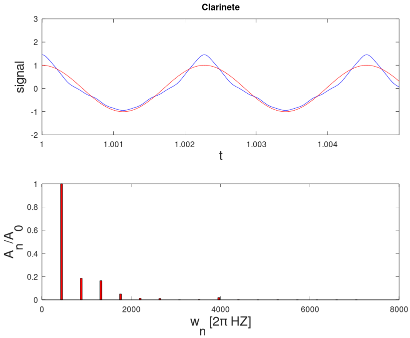
$$A_n(w_n) \quad Determines \quad wave \quad shape$$

Sound spectra for different instruments

$$A_n \text{ vs. } w_n$$





Beats—Interference in Time

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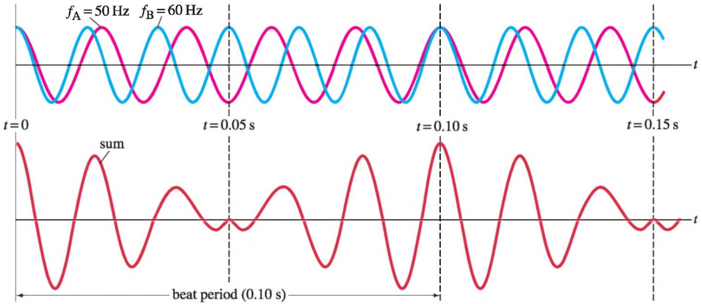

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The resultant displacement is,

$$D = D_1 + D_2 = A[Asin(2\pi f_1 t) + sin(2\pi f_1 t)]$$

Beats, Interference in Time

Using, $sin\theta_1 + sin\theta_2 = 2sin\frac{1}{2}(\theta_1 + \theta_2)cos\frac{1}{2}(\theta_1 - \theta_2)$

Beats, Interference in Time

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$$D = \left[2Acos2\pi\left(\frac{f_1 - f_2}{2}\right)t\right]sin2\pi\left(\frac{f_1 + f_2}{2}\right)t \qquad (10)$$

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$\rightarrow$ two beats occur per cycle $\rightarrow$ beat frequency is $f_1 - f_2$.