Unit 2: Waves

Part II

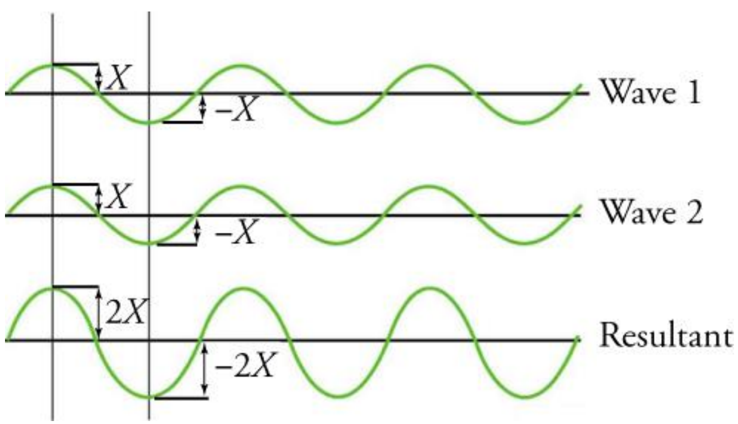
Interactions of two or more waves

- Superposition of Waves – adding of individual waves magnitudes to form the resultant wave pattern

Wave Interference

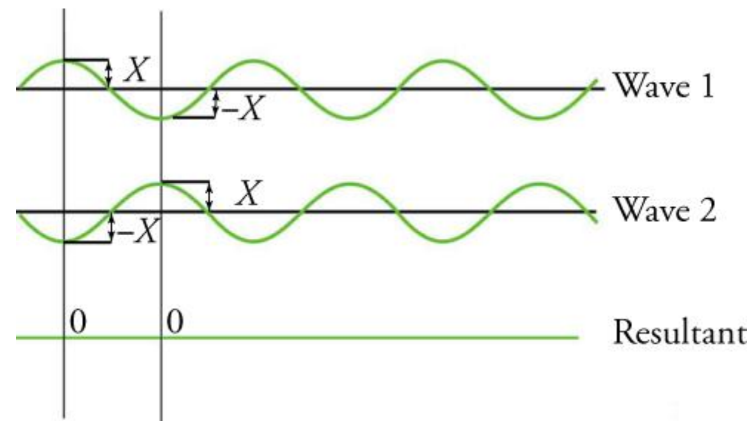
Constructive interference

-occurs when two identical waves (frequency and amplitude) arrive at the same point exactly ***in phase***.



Destructive interference

-occurs when two identical waves that arrive exactly **out of phase**

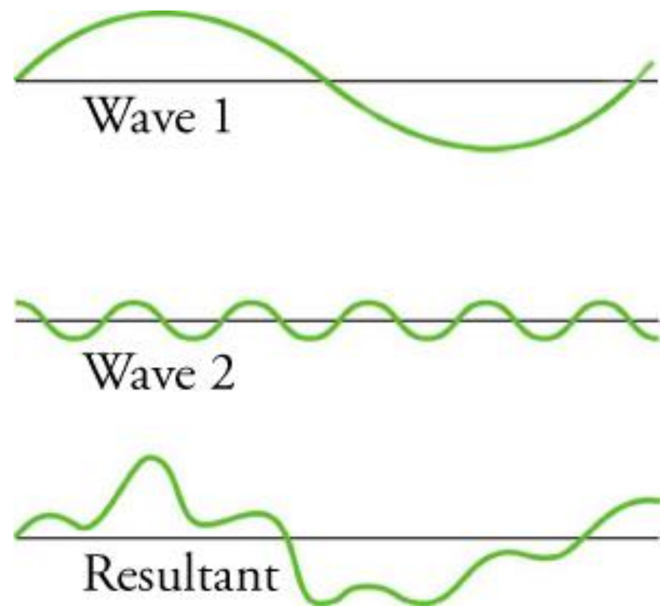


Video illustration: https://www.youtube.com/watch?v=CAe3lkYNKt8

Simulation of waves: https://phet.colorado.edu/sims/html/wave-interference/latest/wave-interference_en.html

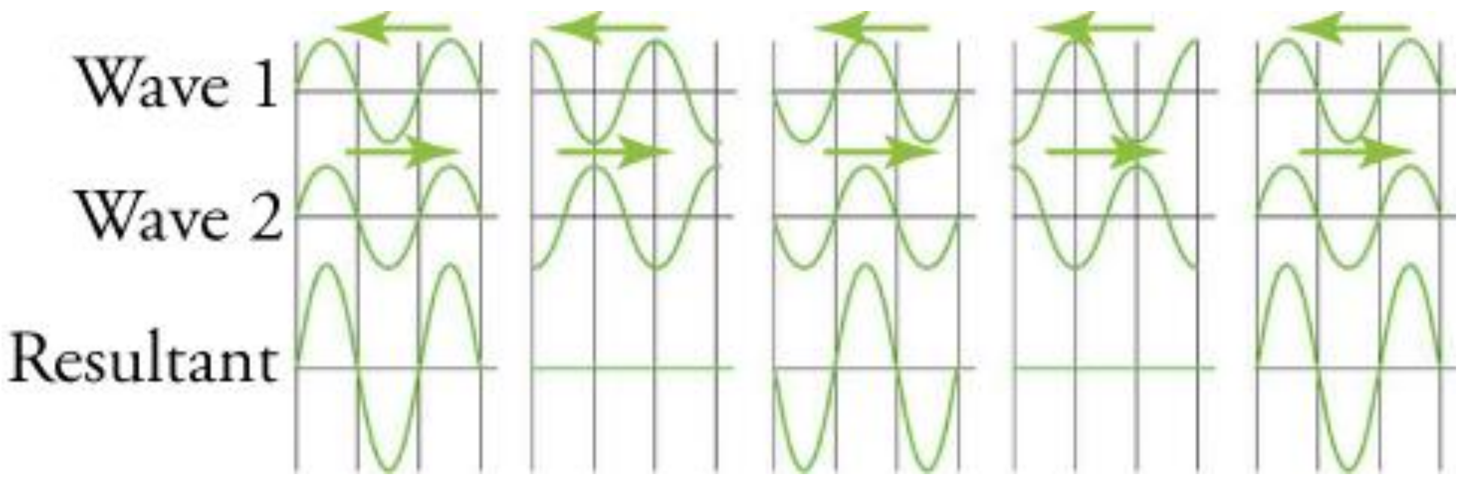
Superposition of non-identical waves

- when two waves that are not similar, that is, having different amplitudes and wavelengths, the resultant wave from the combined disturbances of two dissimilar waves looks much different than the idealized sinusoidal shape of a periodic wave.



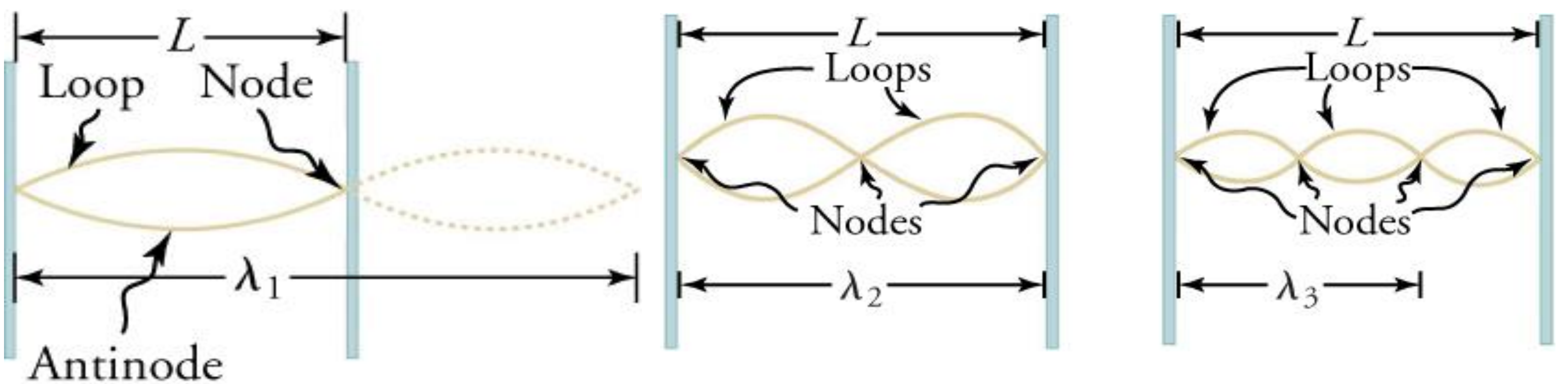
Standing Waves

- They are formed by the superposition of two or more waves moving in opposite directions.
- The waves move through each other with their disturbances adding as they go by.
- If the two waves have the same amplitude and wavelength, then they alternate between constructive and destructive interference.



Standing Waves

- It can be found on the strings of musical instruments and are due to reflections of waves from the ends of the string.
- **Reflection** is the change in direction of a wave when it bounces off a barrier, such as a fixed end.
- As it is reflected, the wave experiences an **inversion**, which means that it flips vertically.



Video illustration: https://www.youtube.com/watch?v=PVX4V5Adbzk

Standing Waves - examples

- Guitar strings: https://www.youtube.com/watch?v=qi-f68A_-eg
- Ultrasonic levitation: https://www.youtube.com/watch?v=gTNOlqLmmiE
- Microwave cooker: https://www.youtube.com/watch?v=kp33ZprO0Ck&t=105s (at time: 2:19min)

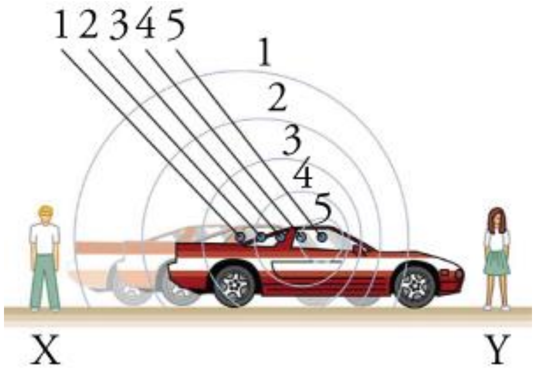
Doppler Effect

- It is a change in the observed pitch (frequency) of a sound, due to relative motion between the source and the observer.
- An example of the Doppler effect with a stationary source and moving observer is if you ride a train past a stationary warning bell, you will hear the bell's frequency shift from high to low as you pass by.

Video: https://www.youtube.com/watch?v=h4OnBYrbCjY @1:12

What courses the Doppler effect?

- It is due a change of wavelength as a results of a change between the distance of the source and the observer.
- Considering the following three situations:



- Sounds emitted by a source spread out in spherical waves.
- the source, observers, and air are stationary,
- the wavelength and frequency are the same in all directions and to all observers.

- Sounds emitted by a source moving to the right spread out from the points at which they were emitted.
- The wavelength is reduced and, the frequency is increased in the direction of motion, so that the observer on the right hears a higher-pitch sound.

- The same effect is produced when the observers move relative to the source.
- Motion toward the source increases frequency as the observer on the right passes through more wave crests than she would if stationary.

Frequency shift in Doppler Effect

- For a stationary observer and a moving source of sound, the frequency (f_{obs}) of sound perceived by the observer is

$$f_{obs} = f_s \left(\frac{v_w}{v_w \pm v_s} \right)$$

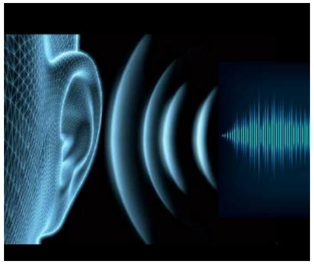
  - f_s is the frequency of sound from a source
  - v_s is the speed of the source along a line joining the source and observer
  - v_w is the speed of sound
  - "-" sign is used for motion toward the observer and the "+" sign for motion away from the observer.

- Similarly, for a stationary source and moving observer, the frequency perceived by the observer f_{obs} is given by

$$f_{obs} = f_s \left(\frac{v_w \pm v_{obs}}{v_w} \right)$$

  - v_{obs} is the speed of the observer along a line joining the source and observer.

What is Acoustics and Sound?



- It is a branch of physics that deals with the study of mechanical waves in gases, liquids, and solids including topics such as vibration, sound, ultrasound and infrasound.
- Since sound is a wave, we can relate the properties of sound to the properties of a wave.
- Humans can normally hear frequencies ranging from approximately 20 to 20,000 Hz.
- Sounds below 20 Hz are called infrasound, whereas those above 20,000 Hz are ultrasound.
- **Hearing** is the perception of sound. It can give us plenty of information—such as pitch, loudness, and direction.
- The perception of intensity is called **loudness** and the perception of frequency is called **pitch**

Ref: https://openstax.org/books/physics/pages/14-2-sound-intensity-and-sound-level

Units of sound intensity

- A useful quantity for describing the loudness of sounds is called **sound intensity.**
- It is the power per unit area carried by the wave. Power is the rate at which energy is transferred by the wave. (since sound is a wave)
- Mathematically, it can be expressed as $I = \frac{P}{A}$

  where P is the power through an area A. The SI unit of I is W/m^2.

- Since the intensity of a sound also depends upon its pressure amplitude.
- The relationship between the intensity of a sound wave and its pressure amplitude (or pressure variation Δ*ρ*) is

$$I = \frac{(\Delta p)^2}{2\rho v_w}$$

where *ρ* is the density of the materials in which the sound travels (kg/m3) and *v* is the velocity of sound (m/s), pressure amplitude has units of Pascals (Pa or N/m)

The Decibel Scale

- Loudness of a sound may also express in units of decibels rather watts per meter squared.
- While sound intensity (in W/m^2) is the SI unit, the **sound intensity level** in decibels (dB) is more relevant for how humans perceive sounds.
- The way our ears perceive sound can be more accurately described by the logarithm of the intensity of a sound rather than the intensity of a sound directly.
- The sound intensity level β is defined to be

$$\beta\ (\mathrm{dB}) = 10 \log_{10}\left(\frac{I}{I_0}\right)$$

where where I is sound intensity in watts per meter squared, and $I_0 = 10^{-12}\ W/m^2$ is a reference intensity.

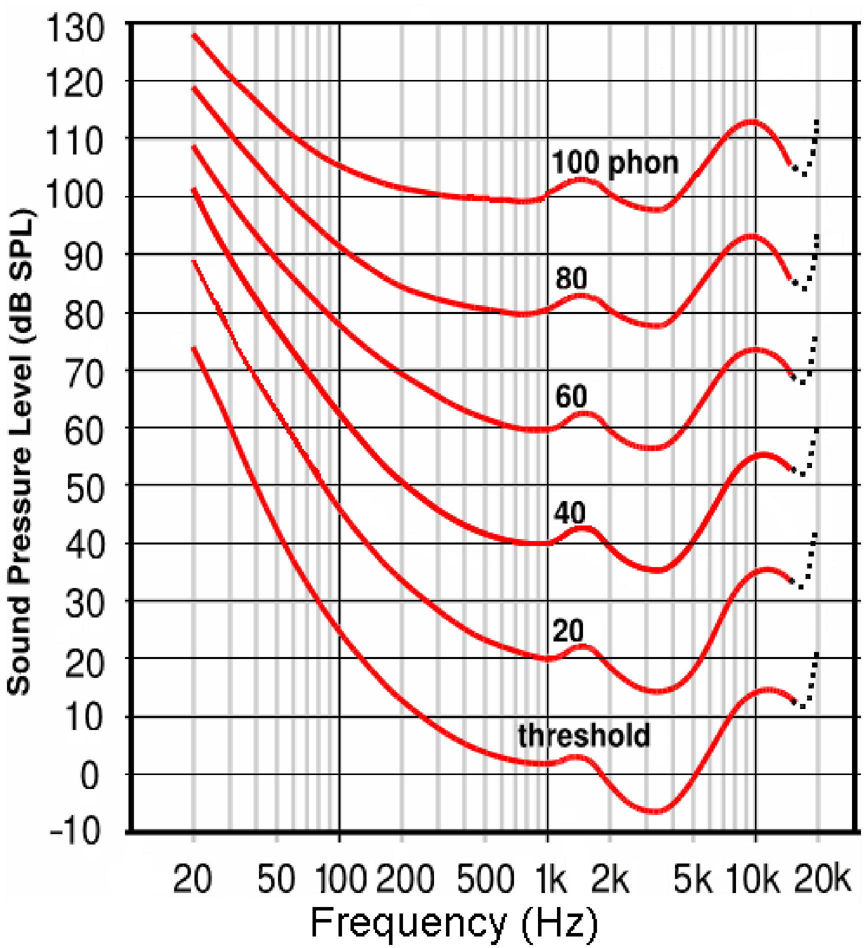
The Decibel Scale

- Each factor of 10 in intensity corresponds to 10 dB. For example, a 90 dB sound compared with a 60 dB sound is 30 dB greater, or three factors of 10 (that is, 10^3 times) as intense.
- Another example is that if one sound is 10^7 as intense as another, it is 70 dB higher.
- Since β is defined in terms of a ratio, it is unit-less.
- As an example, if we double the sound intensity, the sound level increases by 3dB,

$$\beta\,(\mathrm{dB}) = 10\log_{10}\left(\frac{I}{I_0}\right)$$

Unit of sound loudness - Phon

- Human sensitivity to sound is variable across different frequencies; therefore, although two different tones may have identical sound intensity, they may be psycho-acoustically perceived as differing in loudness.
- The **phon** is a unit of loudness for pure tones. The purpose of the phon is to provide a standard measurement for perceived intensity.
- The phon is psycho-physically matched to a reference frequency of 1 kHz. For instance, if a sound is perceived to be equal in intensity to a 1 kHz tone with an SPL of 50 dB, then it has a loudness of 50 phons.



Equal-loudness Curves ISO 226:2003

Ref: https://en.wikipedia.org/wiki/Phon

The difference between frequency and pitch

- Pitch is an auditory sensation in which a listener assigns musical tones to relative positions on a musical scale based primarily on their perception of the frequency of vibration.
- Pitch is closely related to frequency, but the two are not equivalent.
- Frequency is an objective, scientific attribute that can be measured.
- Pitch is each person's *subjective perception* of a sound wave, which cannot be directly measured.
- However, this does not necessarily mean that most people won't agree on which notes are higher and lower.

Ref: https://en.wikipedia.org/wiki/Pitch_(music)

Musical scales and frequencies

- A musical octave spans a factor of two in frequency and there are twelve notes per octave.
- Starting at any note the frequency to other notes may be calculated from its frequency by:

  Freq = note x $2^{N/12}$

Notes	Frequency (octaves)				
A	55.00	110.00	220.00	440.00	880.00
A#	58.27	116.54	233.08	466.16	932.32
B	61.74	123.48	246.96	493.92	987.84
C	65.41	130.82	261.64	523.28	1046.56
C#	69.30	138.60	277.20	554.40	1108.80
D	73.42	146.84	293.68	587.36	1174.72
D#	77.78	155.56	311.12	622.24	1244.48
E	82.41	164.82	329.64	659.28	1318.56
F	87.31	174.62	349.24	698.48	1396.96
F#	92.50	185.00	370.00	740.00	1480.00
G	98.00	196.00	392.00	784.00	1568.00
A♭	103.83	207.66	415.32	830.64	1661.28

http://www.techlib.com/reference/musical_note_frequencies.htm#:~:text=Starting%20at%20any%20note%20the,be%20positive%2C%20negative%20or%20zero.