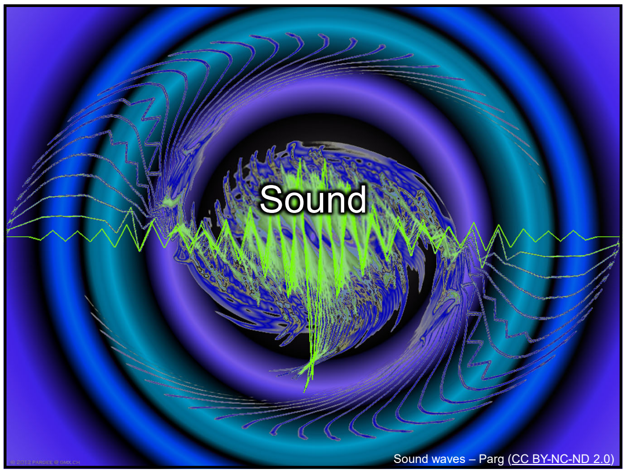
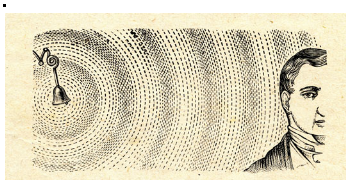


Sound waves – Parg (CC BY-NC-ND 2.0)

Sound Waves

- Sound waves are produced by vibrations.
- The vibrating source moves the nearby air particles sending a disturbance through the surrounding medium as a longitudinal wave.



Juulijs (Adobe Stock)

Speed of Sound

- The speed of sound depends on the type of medium (solid, liquid, gas) and the temperature of the medium.
  - $v_{solids} > v_{liquids} > v_{gasses}$
  - Sound travels slower as the temperature decreases.
- In dry air… $v = 331 + 0.6T$

Where:
v is the speed of sound
T is the temperature in °C

Speed of Sound in Different Media at 25°C

State	Substance	Speed in m/s
Gas	Air	346
	Oxygen	316
	Helium	965
Liquid	Distilled Water	1498
	Sea Water	1531
	Ethanol	1207
Solid	Aluminum	6420
	Steel	5690
	Glass	3980

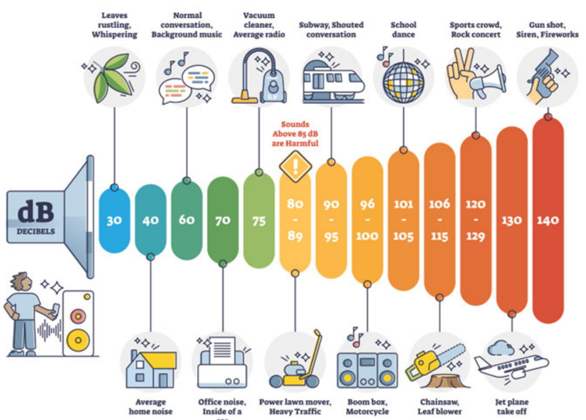
Loudness

- The loudness of a sound is related to how energetically its source is vibrating.
- A useful quantity for describing the loudness of sounds is called sound intensity.
  - In general, the intensity of a wave is the power per unit area carried by the wave.
  - Power is the rate at which energy is transferred by the wave.

- Sound intensity is proportional to the square of the amplitude.
  - $I \propto A^2$
- Sound intensity level, measured in decibels (dB) is more relevant for how humans perceive sound.
  - The decibel scale (dB) is a log-based scale relative to the quietest sound a human can perceive.
    - A change of 10 dB is the equivalent of an increase of 10x the intensity.
    - A change of 20 dB is the equivalent of an increase in 100 x the intensity.

- A change of 3 dB is the minimum change in sound level to be detected
  - barely noticeable
- A change of between 6 dB and 10 dB is perceived as a doubling (or halving of volume)

- The perception of loudness depends on the frequency of the sound.



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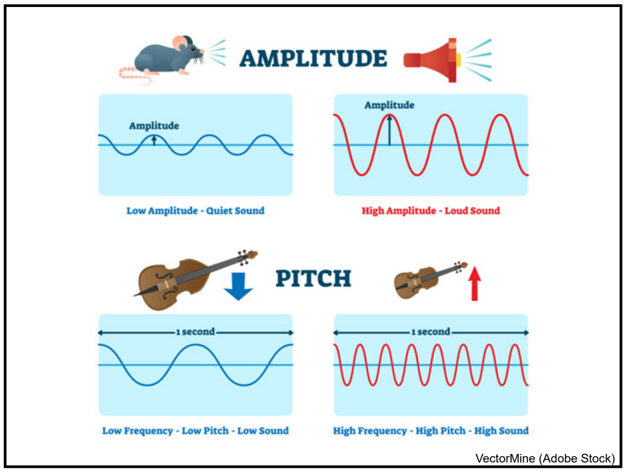
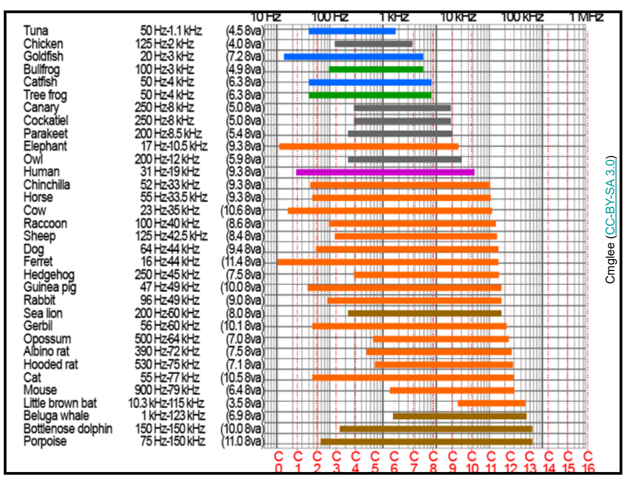
Hearing

- Hearing is the perception of sound.
- The perception of frequency is called pitch, and the perception of intensity is called loudness.


Piano – Steve Buissinne (Pixabay)

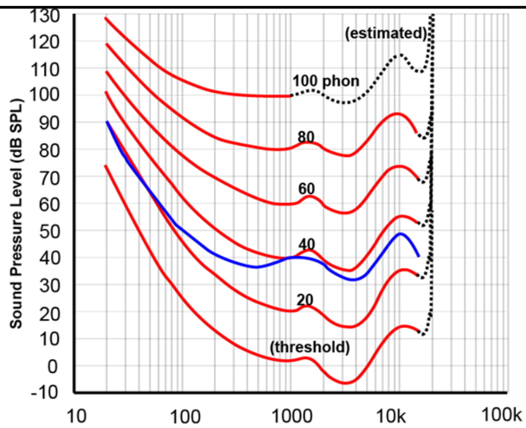


- Every animal can hear sounds over a different range of frequencies.
  - Humans: 20 – 20 kHz
  - Dogs: 40 – 60 kHz
  - Cats: 45 – 64 kHz
  - Bats: 20 – 120 kHz
  - Mice: 1000 – 90 kHz
  - Chickens: 125 – 2000 Hz



- While humans can hear frequencies from 20 – 20 kHz, the ear is not equally sensitive to all frequencies.
  - The human ear is most sensitive between 2 and 5 kHz.
- The first research on the topic of how the ear hears different frequencies at different levels was conducted by Harvey Fletcher (American) and Wilden A. Munson (American) in 1933.

- An equal-loudness contour (curve) is a measure of sound pressure level, over the frequency spectrum, for which a listener perceives a constant loudness when presented with pure steady tones.
  - The Fletcher–Munson curves were the first such curves to be determined experimentally.
  - The current standardized set of curves are those defined in ISO 226.



Equal-loudness contours (red) (from ISO 226:2003 revision)
Original ISO standard shown (blue) for 40-phons

(public domain)

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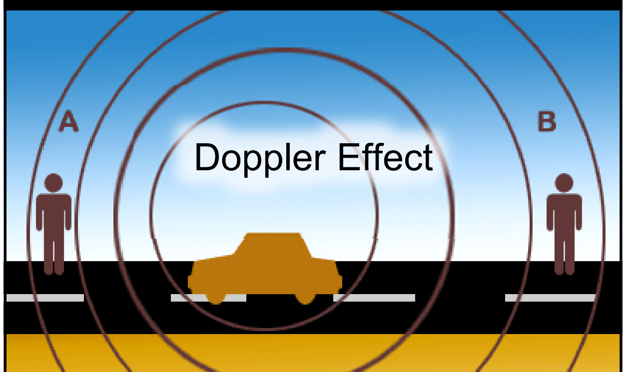
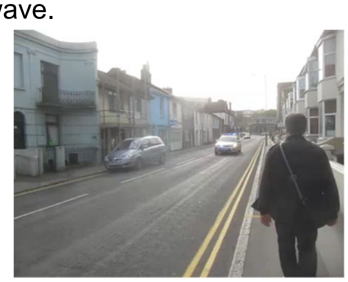


Zappys Technology Solutions (CC BY 2.0)

- When there is relative motion between a source of waves and an observer, the observed frequency of the waves is different to the frequency of the source of the wave.

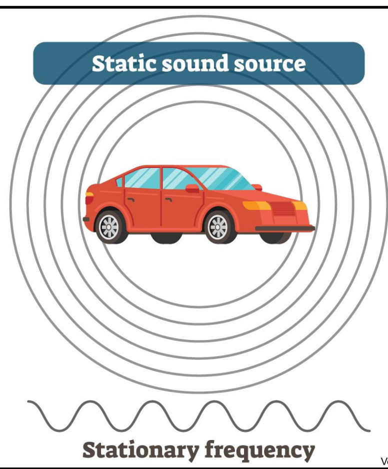


Tantek Çelik (CC BY-NC 2.0)

https://youtu.be/7l1OxhxCh1E

Stationary Source

- Sound waves are produced at a constant frequency f_0, and the wavefronts propagate symmetrically away from the source at a constant speed *v.*
- The distance between wavefronts is the wavelength.
- All observers will hear the same frequency, which will be equal to the actual frequency of the source.



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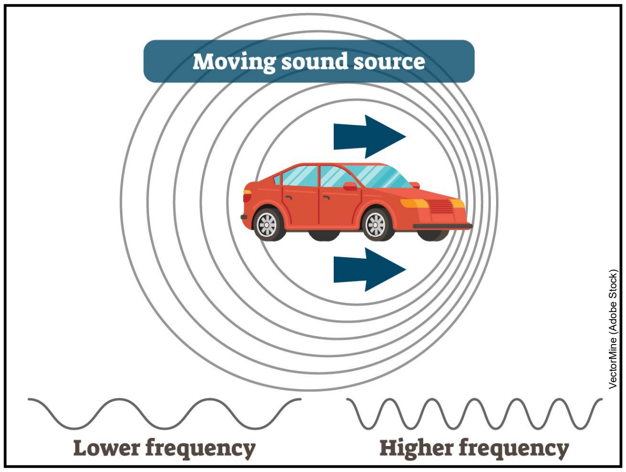
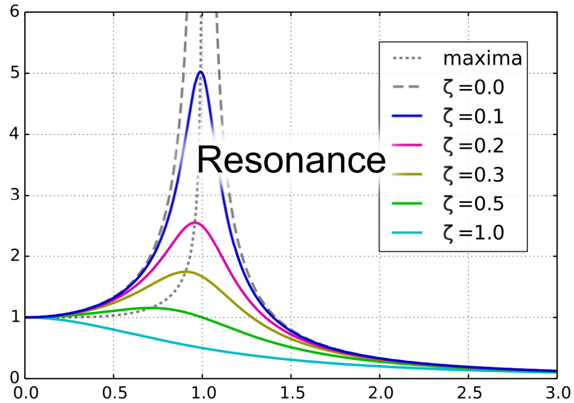
Moving Source

- A source producing the same frequency as before is moving.
- The center of each new wavefront is now slightly displaced in the direction of the motion.
- The wavefronts begin to bunch up in front of and spread further apart behind the source.
- An observer in front of the source will hear a higher frequency $f' > f_0$, and an observer behind the source will hear a lower frequency $f' < f_0$.

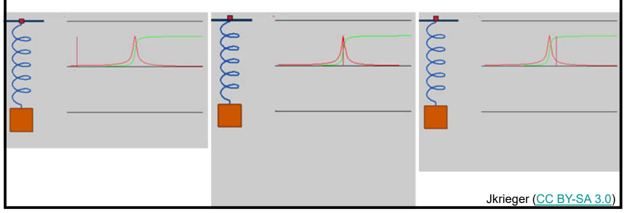


https://youtu.be/Tn35SB1_NYI



- When a mechanical system is forced to oscillate by a driving force that has the same frequency as the natural frequency (f_0) of the mechanical system, it will vibrate with maximum amplitude.
- This is called resonance.

$f < f_0$ $f = f_0$ $f > f_0$



Resonance can be bad…

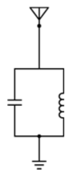
AirMan454. PA-30 Twin Commanche Tail Flutter Test. NASA 1966

Resonance can also be good…

- Microwave ovens
  - Microwaves force oscillation of water molecules inside the food, generating heat.

Kurman Communications (CC BY 2.0)

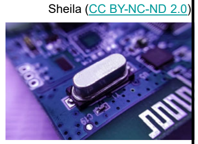
- Radios/Televisions
  - The tuner selects the station by resonating at one frequency.



Skylar Kang (Pexels)

- Quartz oscillators
  - A thin wafer of quartz, with electrodes attached to opposing surfaces, vibrates mechanically at its resonance frequency when voltage is applied to the two electrodes.

Sheila (CC BY-NC-ND 2.0)



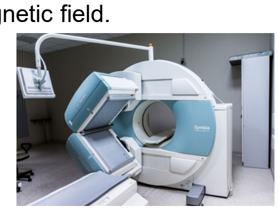
Ismed (Adobe Stock)

- Musical Instruments
  - Musical instruments work by causing air to resonate at various frequencies.

analogicus (Pixabay)

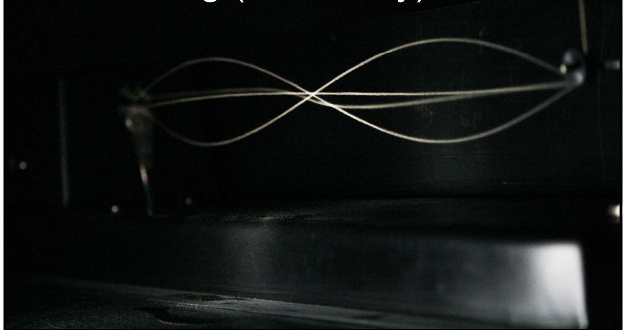
- Magnetic Resonance Imaging (MRI)
  - A strong magnetic field forces protons to align with that field. When a radiofrequency current is pulsed, the protons are stimulated, and spin out of equilibrium. When the radiofrequency field is turned off, the sensors detect the energy released as the protons realign with the magnetic field.

Becky Stern (CC BY-SA 2.0)



Michael Jarmoluk (Pixabay)

Standing (Stationary) Waves



Standing waves – Giacomo Carena (CC BY-ND 2.0)

- Under the right circumstances waves can be formed in which the positions of the crests and the troughs do not change.
- Two travelling waves of equal amplitude and equal frequency travelling with the same speed in opposite directions are superposed.
- This is a standing wave.

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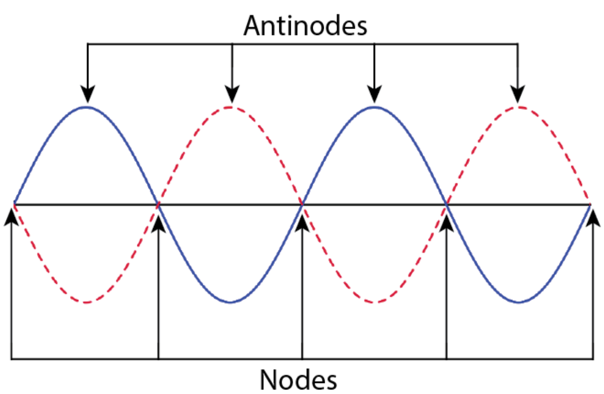
www.walter-fendt.de/html5/phen/standingwavereflection_en.htm

Special Terms

- Node
  - Points where the displacement is ***always*** zero
- Antinode
  - Displacement is a maximum
  - Note: the maximum is not always the same maximum



Harmonics

- We can have different modes of vibration or harmonics.
- The first mode of vibration has the lowest frequency and is called the first harmonic.
- The next modes of vibration are the second harmonic, third harmonic,…
- Each harmonic is an interval of the first harmonic.

$f_2 = 2f_1$ $f_3 = 3f_1$ $f_4 = 4f_1$

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Please enter the URL below.

https:// simbucket.com/standingwaves/

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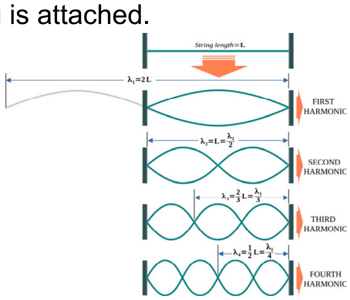
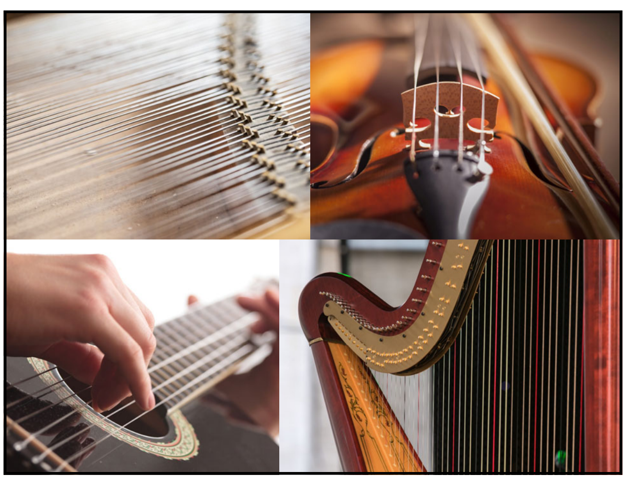
https://simbucket.com/standingwaves/

Standing Waves on a String

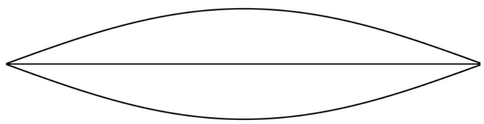
- There is a node at each end where the string is attached.



ScientificStock (Adobe Stock)



- First harmonic (fundamental)

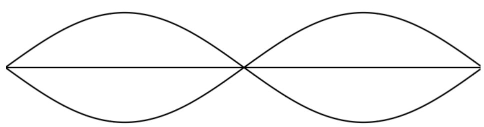


$$L = \frac{\lambda_1}{2}$$

$$f_1 = \frac{v}{\lambda_1} \qquad \lambda_1 = 2L$$

$$f_1 = \frac{v}{2L}$$

- Second harmonic

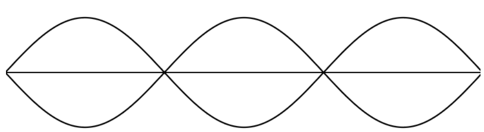


$$L = \frac{2\lambda_2}{2}$$

$$f_2 = \frac{v}{\lambda_2} \qquad \lambda_2 = \frac{2L}{2}$$

$$f_2 = \frac{2v}{2L} = 2f_1$$

- Third harmonic



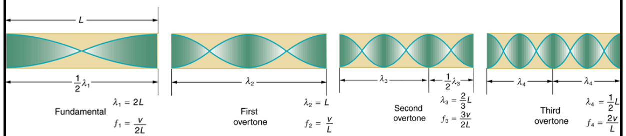
$$L = \frac{3\lambda_3}{2}$$

$$f_3 = \frac{v}{\lambda_3} \qquad \lambda_3 = \frac{2L}{3}$$

$$f_3 = \frac{3v}{2L} = 3f_1$$

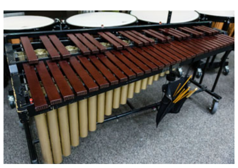
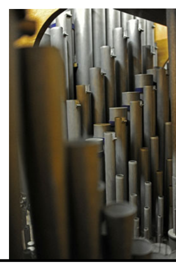
Standing Waves in an Open Pipe

- An open pipe (open at both ends) has an antinode at both ends.
  - It behaves similarly to a string.

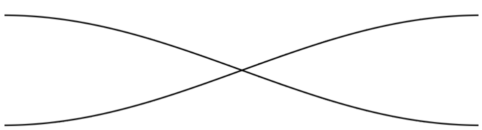






- First harmonic (fundamental)

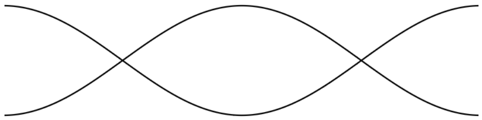


$$L = \frac{\lambda_1}{2}$$

$$f_1 = \frac{v}{\lambda_1} \qquad \lambda_1 = 2L$$

$$f_1 = \frac{v}{2L}$$

- Second harmonic

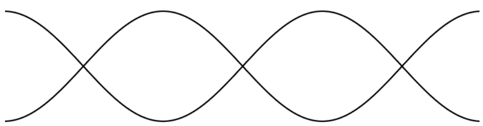


$$L = \frac{2\lambda_2}{2}$$

$$f_2 = \frac{v}{\lambda_2} \qquad \lambda_2 = \frac{2L}{2}$$

$$f_2 = \frac{2v}{2L} = 2f_1$$

- Third harmonic



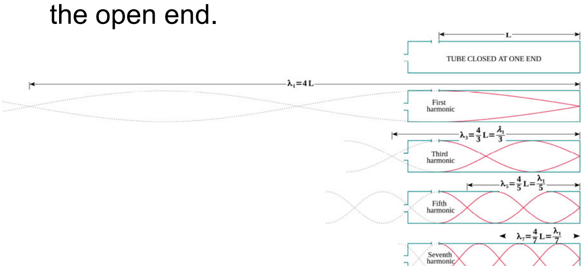
$$L = \frac{3\lambda_3}{2}$$

$$f_3 = \frac{v}{\lambda_3} \qquad \lambda_3 = \frac{2L}{3}$$

$$f_3 = \frac{3v}{2L} = 3f_1$$

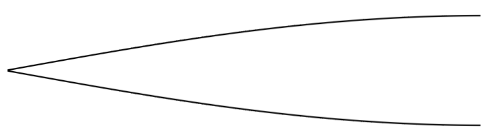
Standing Waves in a Closed Pipe

- A pipe that is closed at one end has a node at the closed end and an antinode at the open end.



ScientificStock (Adobe Stock)

- First harmonic (fundamental)

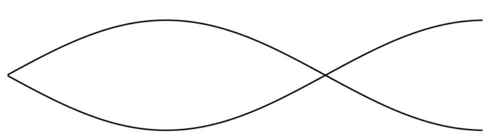


$$L = \frac{\lambda_1}{4}$$

$$f_1 = \frac{v}{\lambda_1} \qquad \lambda_1 = 4L$$

$$f_1 = \frac{v}{4L}$$

- Third harmonic

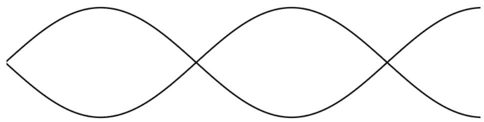


$$L = \frac{3\lambda_3}{4}$$

$$f_3 = \frac{v}{\lambda_3} \qquad \lambda_3 = \frac{4L}{3}$$

$$f_3 = \frac{3v}{4L} = 3f_1$$

- Fifth harmonic



$$L = \frac{5\lambda_5}{4}$$

$$f_5 = \frac{v}{\lambda_5} \qquad \lambda_5 = \frac{4L}{5}$$

$$f_5 = \frac{5v}{4L} = 5f_1$$

Sound: Standing Waves and Resonance

https://youtu.be/wXRNKz0xMOU

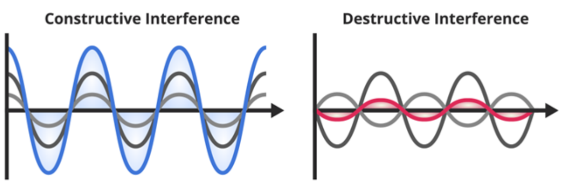
Singing plates - Standing Waves on Chladni plates

https://youtu.be/wYoxOJDrZzw

Interference

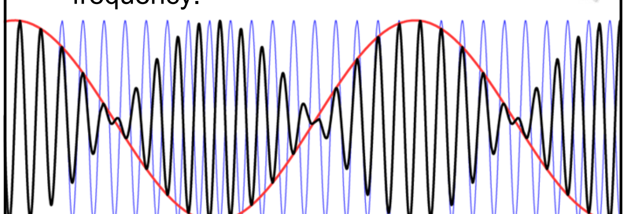
Vibrations – Gerd Altmann (Pixabay)

- When two sound waves meet, they interfere with each other (superposition).
- When the principle of superposition is applied, we have areas of constructive and destructive interference.



petrroudny (Adobe Stock)

- The wave resulting from the superposition of two similar-frequency waves has a frequency that is the average of the two.
- This wave fluctuates in amplitude, or beats, with a frequency called the beat frequency.



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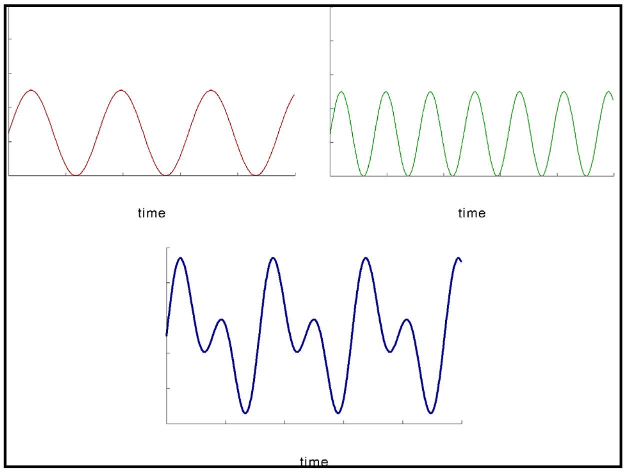
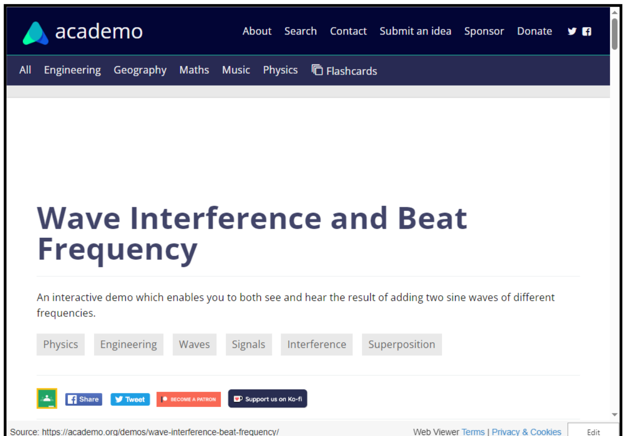
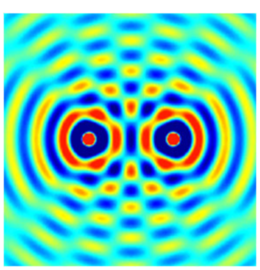




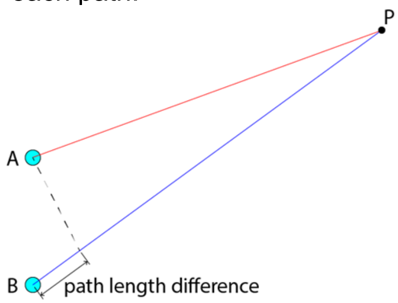
https://academo.org/demos/wave-interference-beat-frequency/

- Waves of equal frequency emitted from two sources will interfere with each other forming areas of destructive and constructive interference.

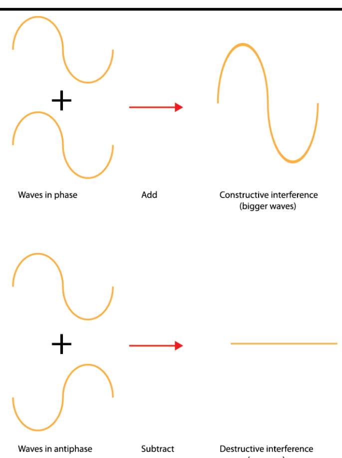


Oleg Alexandrov (Public Domain)

- Each wave travels a different distance from the source to a given point.
- Thus, different numbers of wavelengths fit into each path.

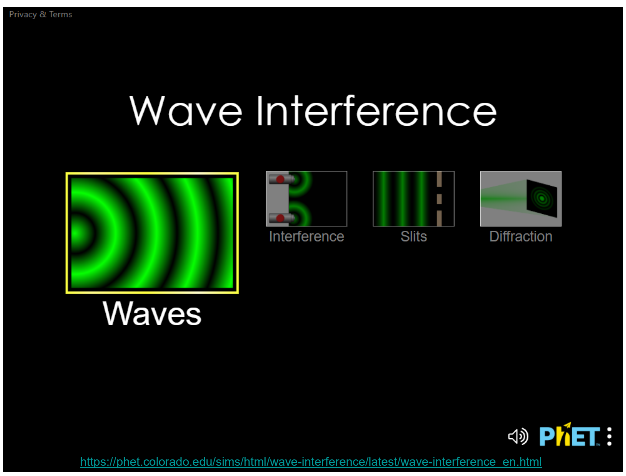


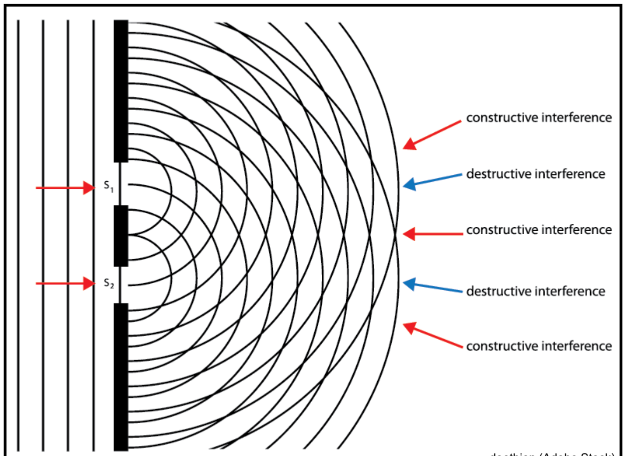
- Waves start out from the sources in phase (crest to crest), but they will end up out of phase (crest to trough) at the point if the paths differ in length by half a wavelength, interfering destructively.
- If the paths differ by a whole wavelength, then the waves arrive in phase (crest to crest) at the point, interfering constructively.



doethion (Adobe Stock)

- More generally, if the paths taken by the two waves differ by any half-integral number of wavelengths $\left(\frac{1}{2}\lambda, \frac{3}{2}\lambda, \frac{5}{2}\lambda, \ldots\right)$, then destructive interference occurs. Similarly, if the paths taken by the two waves differ by any integral number of wavelengths $(\lambda, 2\lambda, 3\lambda, \ldots)$, then constructive interference occurs.





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