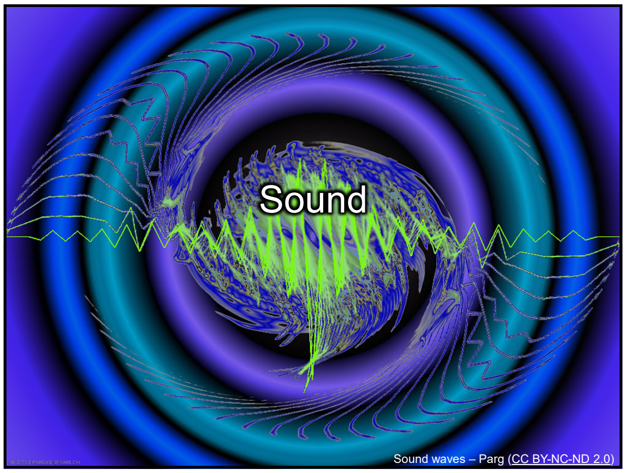
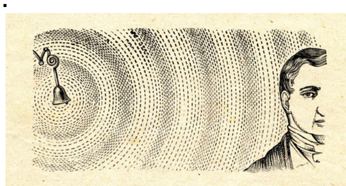


Sound waves – Parg (CC BY-NC-ND 2.0)

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… $\boxed{v = 331 + .06T}$

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

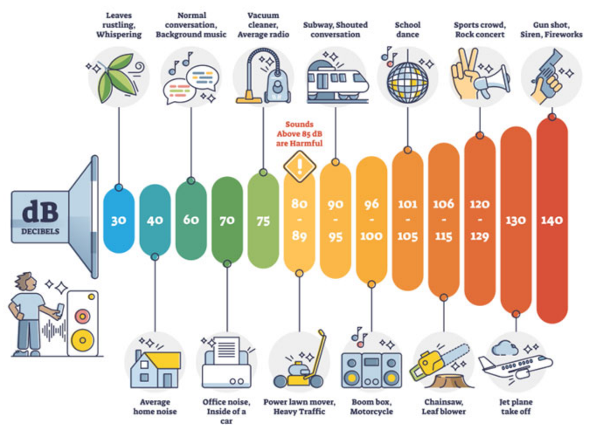
Loudness

- 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.



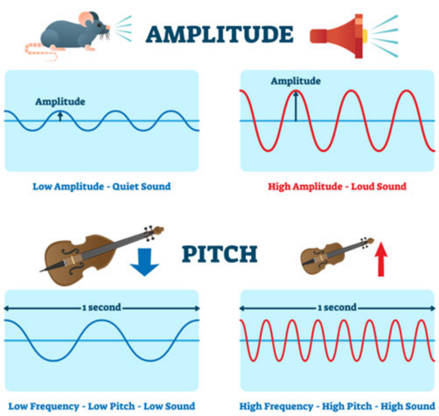
VectorMine (Adobe Stock)

Hearing

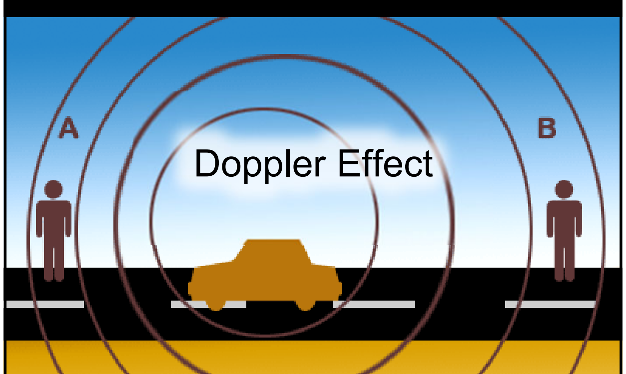
- Hearing is the perception of sound.
- Humans can normally hear frequencies ranging from approximately 20 Hz to 20000 Hz.
  - Other animals can hear different ranges.
    - Dogs: 40 Hz – 60 000 Hz
    - Bats: 20 Hz – 120 000 Hz
    - Mice: 1000 Hz – 90 000 Hz

- Most human speech communication takes place between 200 and 8000 Hz
- The human ear is most sensitive to frequencies around 1000 – 3500 Hz.
- The perception of frequency is called pitch and the perception of intensity is called loudness.

Piano – Steve Buissinne (Pixabay)

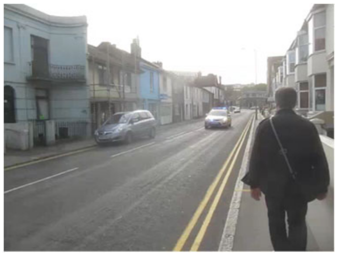


VectorMine (Adobe Stock)



Zappys Technology Solutions (CC BY 2.0)

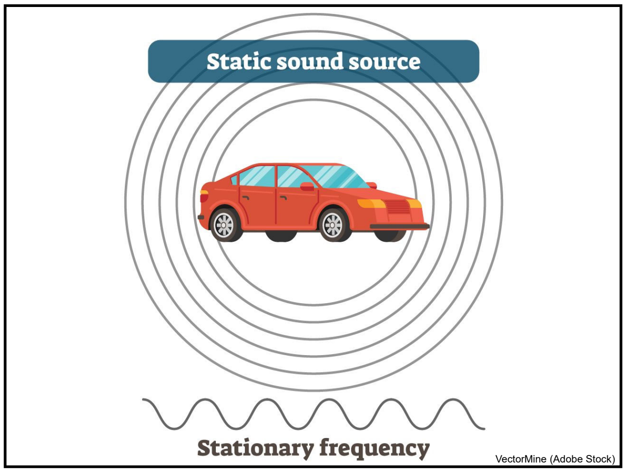
- When there is relative motion between a source of waves and an observer, the observed frequency of the waves is different to the frequency of the source of the wave.



https://youtu.be/7l1OxhxCh1E

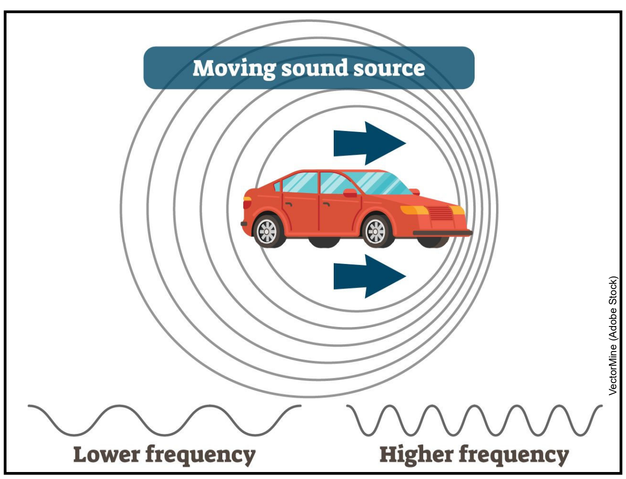
Stationary Source

- 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.



Moving Source

- A source producing the same frequency as before is moving to the right
- The center of each new wavefront is now slightly displaced to the right
- The wavefronts begin to bunch up on the right side (in front of) and spread further apart on the left side (behind) of 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 $f' < f_0$



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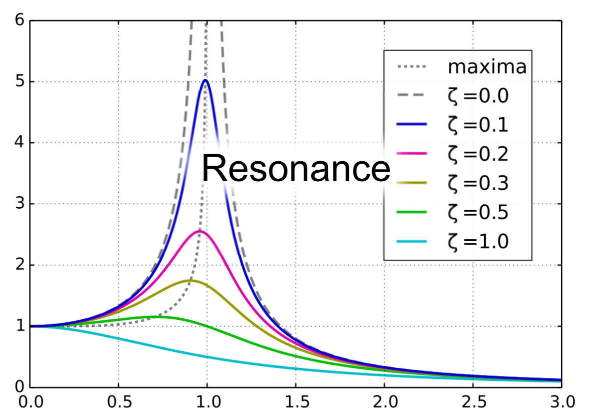
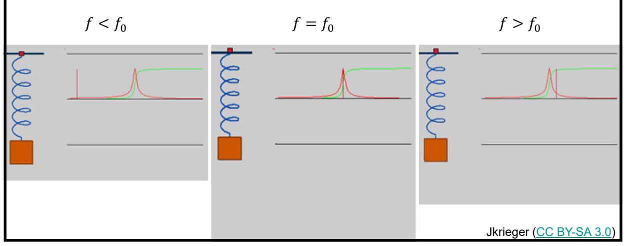


- When a mechanical system is forced to oscillate by a driving force that has the same frequency as the natural frequency (f_0) of the mechanical system, it will vibrate with maximum amplitude.
- This is called resonance.



Resonance can be bad…

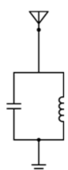
AirMan454. PA-30 Twin Commanche Tail Flutter Test. NASA 1966

Resonance can also be good…

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

Kurman Communications (CC BY 2.0)

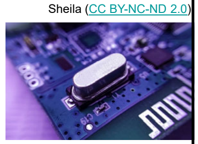
- Radios/Televisions
  - The tuner selects the station by resonating at one frequency.



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)

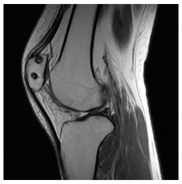


Ismed (Adobe Stock)

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

analogicus (Pixabay)

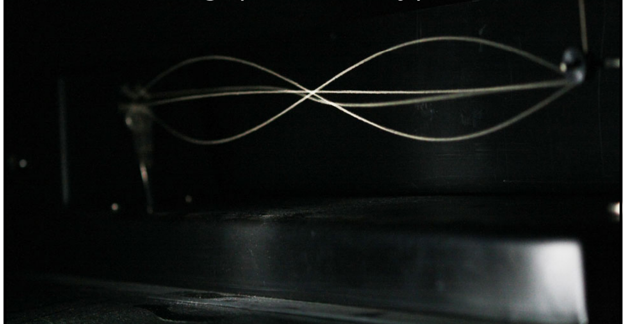
- Magnetic Resonance Imaging (MRI)
  - A strong magnetic field forces protons to align with that field. When a radiofrequency current is pulsed, the protons are stimulated, and spin out of equilibrium. When the radiofrequency field is turned off, the sensors detect the energy released as the protons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



Becky Stern (CC BY-SA 2.0)

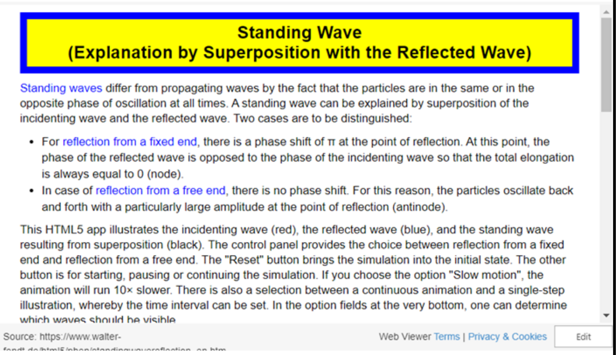
Michael Jarmoluk (Pixabay)

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.



Standing Wave
(Explanation by Superposition with the Reflected Wave)

Standing waves differ from propagating waves by the fact that the particles are in the same or in the opposite phase of oscillation at all times. A standing wave can be explained by superposition of the incidenting wave and the reflected wave. Two cases are to be distinguished:

- For reflection from a fixed end, there is a phase shift of π at the point of reflection. At this point, the phase of the reflected wave is opposed to the phase of the incidenting wave so that the total elongation is always equal to 0 (node).
- In case of reflection from a free end, there is no phase shift. For this reason, the particles oscillate back and forth with a particularly large amplitude at the point of reflection (antinode).

This HTML5 app illustrates the incidenting wave (red), the reflected wave (blue), and the standing wave resulting from superposition (black). The control panel provides the choice between reflection from a fixed end and reflection from a free end. The "Reset" button brings the simulation into the initial state. The other button is for starting, pausing or continuing the simulation. If you choose the option "Slow motion", the animation will run 10× slower. There is also a selection between a continuous animation and a single-step illustration, whereby the time interval can be set. In the option fields at the very bottom, one can determine which waves should be visible

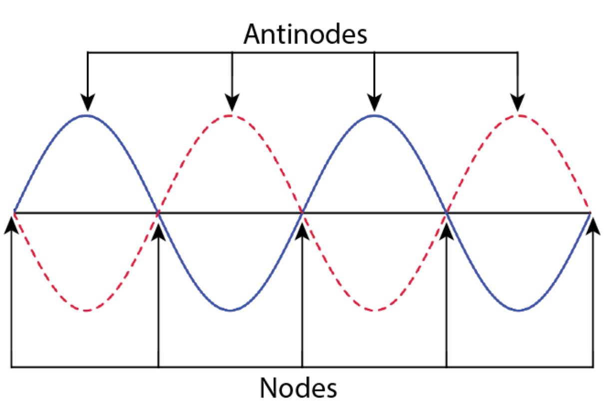
Source: https://www.walter-

Web Viewer Terms | Privacy & Cookies Edit

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

Special Terms

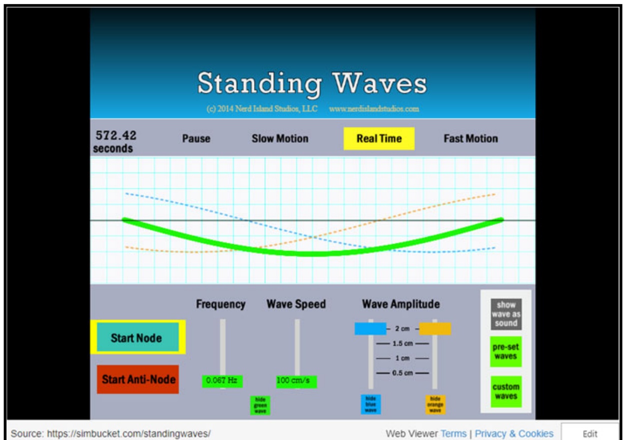
- Node
  - Points where the displacement is ***always*** zero
- Antinode
  - Displacement is a maximum
  - Note: the maximum is not always the same maximum



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.

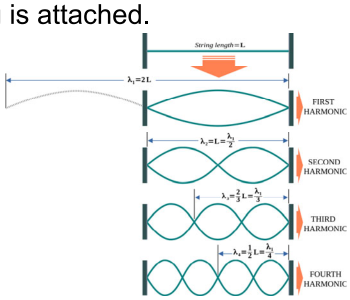
$f_2 = 2f_1$ $f_3 = 3f_1$ $f_4 = 4f_1$



https://simbucket.com/standingwaves/

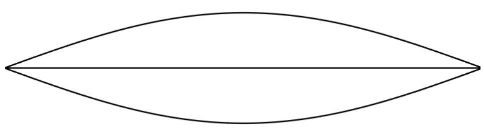
Standing Waves on a String

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



ScientificStock (Adobe Stock)

- First harmonic (fundamental)

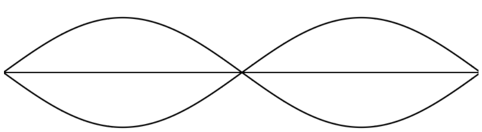


$$L = \frac{\lambda_1}{2}$$

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

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

- Second harmonic

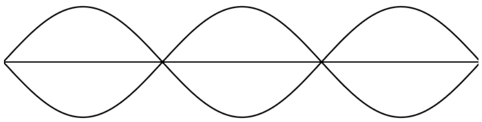


$$L = \frac{2\lambda_2}{2}$$

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

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

- Third harmonic



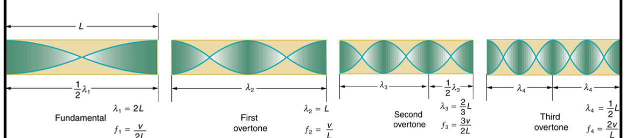
$$L = \frac{3\lambda_3}{2}$$

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

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

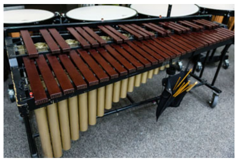
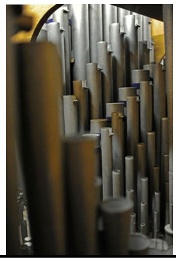
Standing Waves in an Open Pipe

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

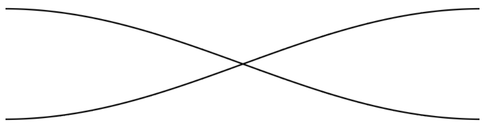






- First harmonic (fundamental)

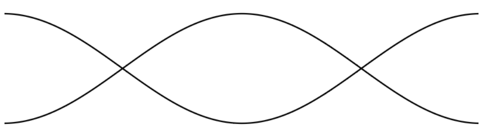


$$L = \frac{\lambda_1}{2}$$

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

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

- Second harmonic

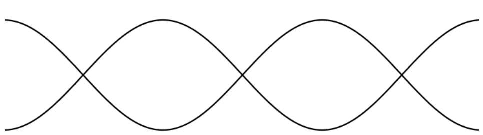


$$L = \frac{2\lambda_2}{2}$$

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

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

- Third harmonic



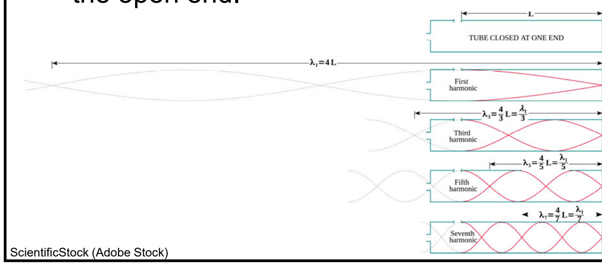
$$L = \frac{3\lambda_3}{2}$$

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

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

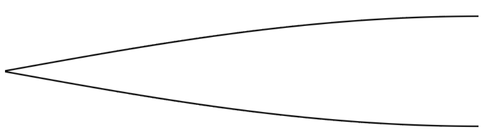
Standing Waves in a Closed Pipe

- 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)

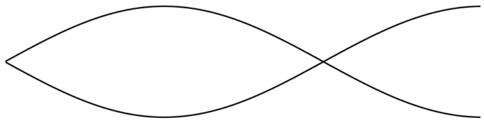


$$L = \frac{\lambda_1}{4}$$

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

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

- Third harmonic

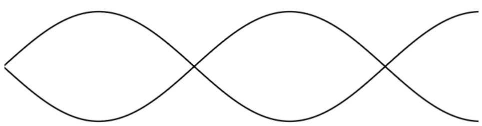


$$L = \frac{3\lambda_3}{4}$$

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

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

- 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

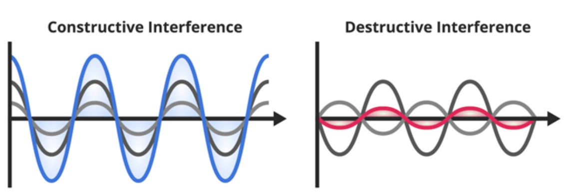
https://youtu.be/wXRNKz0xMOU

Singing plates - Standing Waves on Chladni plates

https://youtu.be/wYoxOJDrZzw

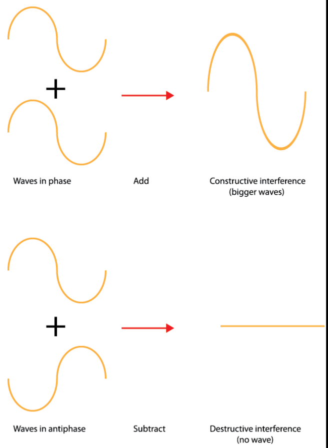
Vibrations – Gerd Altmann (Pixabay)

- 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.



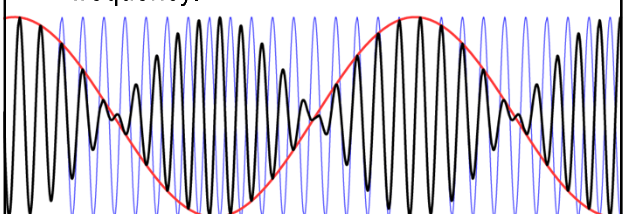
petrroudny (Adobe Stock)

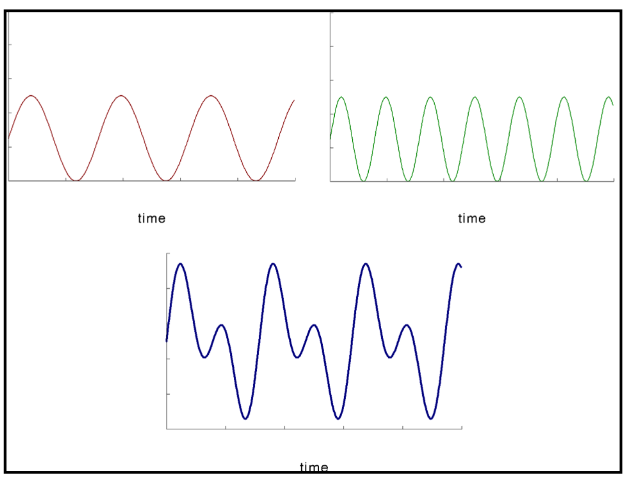
- Waves with the exact same frequency that are in phase add to give twice the amplitude.
- Waves with the exact same frequency that are 180° out of phase add to get zero.

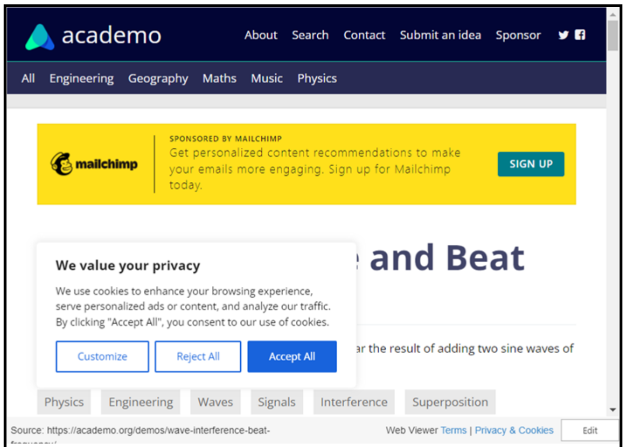


doethion (Adobe Stock)

- 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.

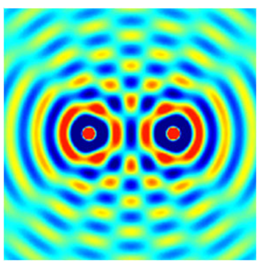






https://academo.org/demos/wave-interference-beat-frequency/

- Interference can also occur when waves are emitted from two sources.
- The waves superpose forming areas of destructive and constructive interference.



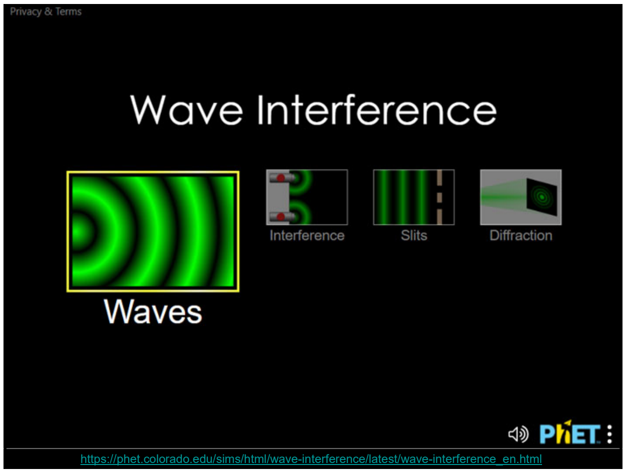
Oleg Alexandrov (Public Domain)

- Constructive interference occurs when the path length difference is a factor of a whole wavelength.

$$|PS_1 - PS_2| = n\lambda$$

- Destructive interference occurs when the path length difference is a factor of one-half wavelength.

$$|PS_1 - PS_2| = \left(n - \frac{1}{2}\right)\lambda$$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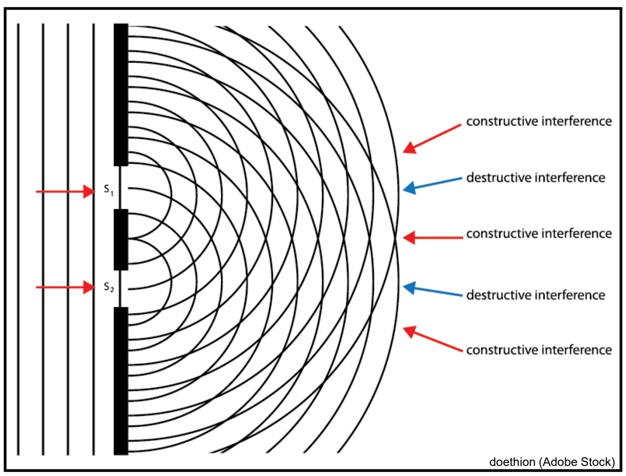
Wave Interference
Interference
Slits
Diffraction
Waves
PhET
https://phet.colorado.edu/sims/html/wave-interference/latest/wave-interference_en.html


constructive interference
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