

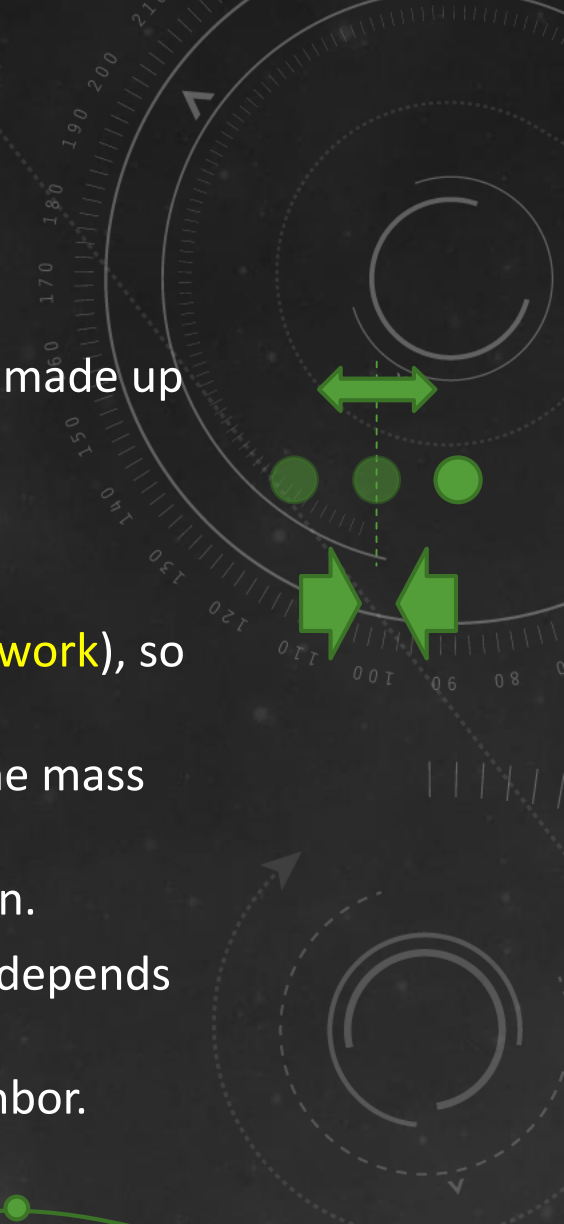


MECHANICAL WAVES

PES 1000 – PHYSICS IN EVERYDAY LIFE

THE BASIC PHYSICS BEHIND WAVES

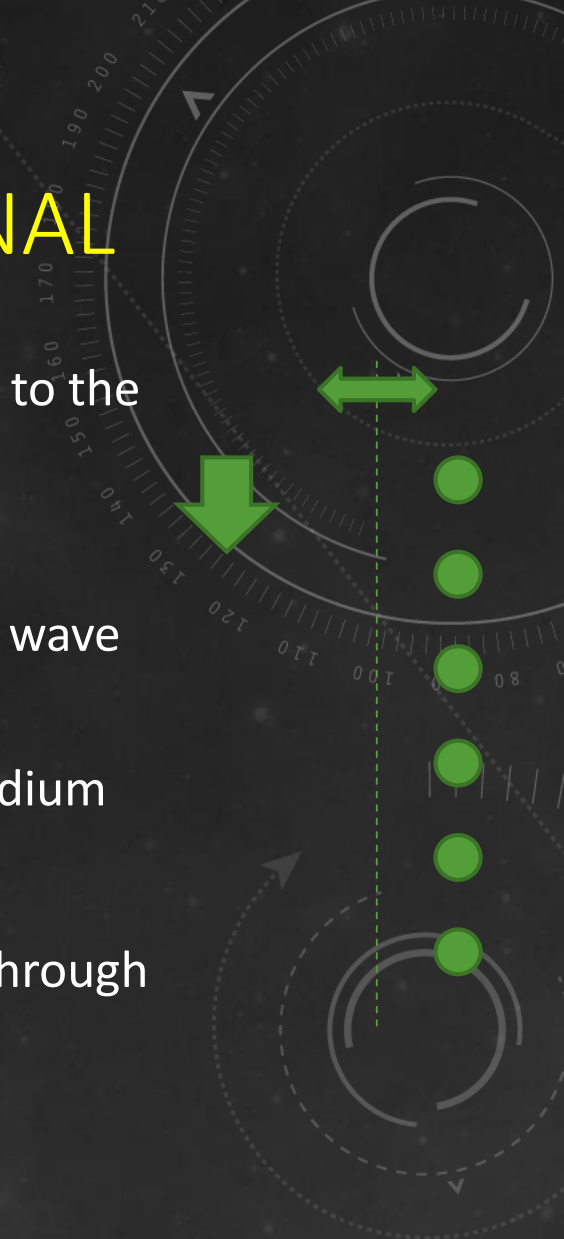
- **Mechanical waves** refer to displacement away from equilibrium of a **physical medium** (made up of particles with mass).
- A particle in equilibrium has the all forces on it in balance.
- Particles in the medium move **back and forth around their equilibrium** position.
- Moving the mass from equilibrium requires exerting a **force through a distance** (doing **work**), so the disturbance contains **energy**.
- Once displaced (or disturbed) from equilibrium, there is a **restoring force** that drives the mass back toward equilibrium.
- **Inertia** carries the particle past equilibrium until the restoring force reverses the motion.
- The **energy** moves away from the initial disturbance (disburses) at some **speed**, which depends on characteristics of the medium (tension, density, etc.).
- Each particle is in a slightly different location in its **cycle** compared to its previous neighbor.



TYPES OF WAVES: TRANSVERSE VS. LONGITUDINAL

There are two types of waves, depending on the motion of the particles with respect to the motion of the wave itself:

- **Transverse**
 - In a transverse wave, the particles move **perpendicular to the direction** of the wave through the medium.
 - Examples: string, water surface waves, a crowd performing 'the wave' in a stadium
- **Longitudinal**
 - In a longitudinal wave, the particles move in the **same direction** as the wave through the medium.
 - Examples: sound waves, slinky compressions

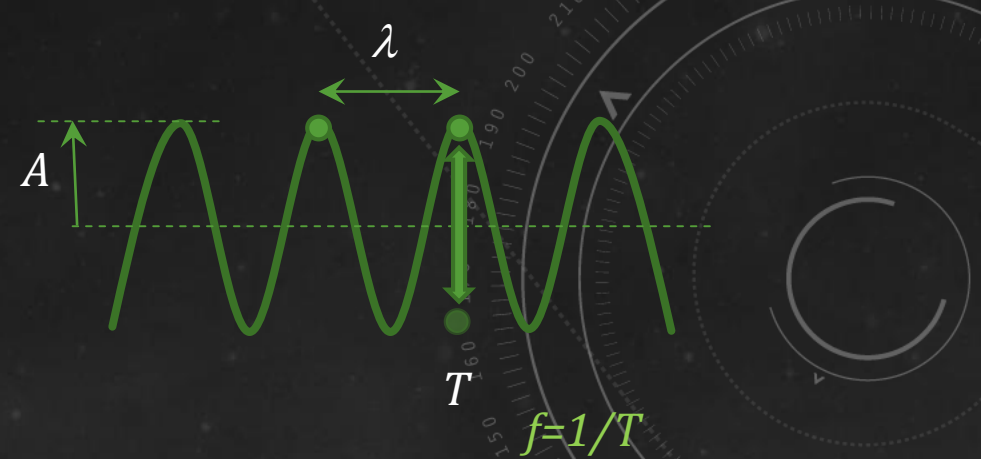


PULSES AND PERIODIC WAVES

- What is a **pulse**?
 - A **single displacement** of the medium, which then quickly returns to equilibrium after wave energy passes.
- During an explosion, a compression wave pulse travels outward at the speed of sound.
 - In this Mythbusters explosion clip, you can see the compressed air bending the light from the background:
<https://www.youtube.com/embed/qx7iijLIItM?start=19&end=25>
- A series of closely spaced, **regular pulses** produces a **periodic wave**.



SINUSOIDAL WAVES



In a **sinusoidal wave**, each particle cycles like a mass on a spring.

- **Period** – The **time** for any particle **to complete one full cycle**.
 - The variable is usually T , and is measured in **seconds**.
 - The period is independent of the size of the initial displacement.
- **Frequency** – The **number of cycles** that a particular particle goes through **in one second**.
 - The variable is usually f , and is measured in cycles per second, or **Hertz (Hz)**.
 - Frequency is the reciprocal of period. A long period is a low frequency, and vice versa.
- **Wavelength** – The shortest **distance between two particles that are at the same place in their cycle**.
 - Often, the variable is λ , and is measured in **meters (SI)** or other convenient length units.
- **Amplitude** – This is the **maximum displacement** any particle has from its equilibrium position.
 - The variable sometimes used is A . It is measured in **meters (SI)** or other convenient length units.
 - The **amplitude does depend on the energy** in the system (initial displacement).

Speed is related to frequency and wavelength by:

$$v = f * \lambda$$

PERIODIC WAVES IN A STRING

Imagine a **string**, fixed at both ends, and **under tension**.

- Producing waves in the string requires **energy** to displace some part of the string from its straight-line equilibrium position. This energy then travels along the string.
- Each part of the string moves **perpendicular** to the string itself, so this wave is **transverse**.
- The **speed** of wave in the string depends on two properties of the string:
 - The **tension**, T – the restoring force that causes the particle to move back toward equilibrium
 - The **density of the string**, μ – a more massive string has more inertia and is harder to move back toward equilibrium. (μ is measured in kg/m.)
 - The equation for the speed of the wave is: $v = \sqrt{T/\mu}$
- It is easy to see **properties of the wave** (wavelength, amplitude, frequency) simply by observing the string's motion (perhaps using slow motion or a strobe light).



PERIODIC SOUND WAVES

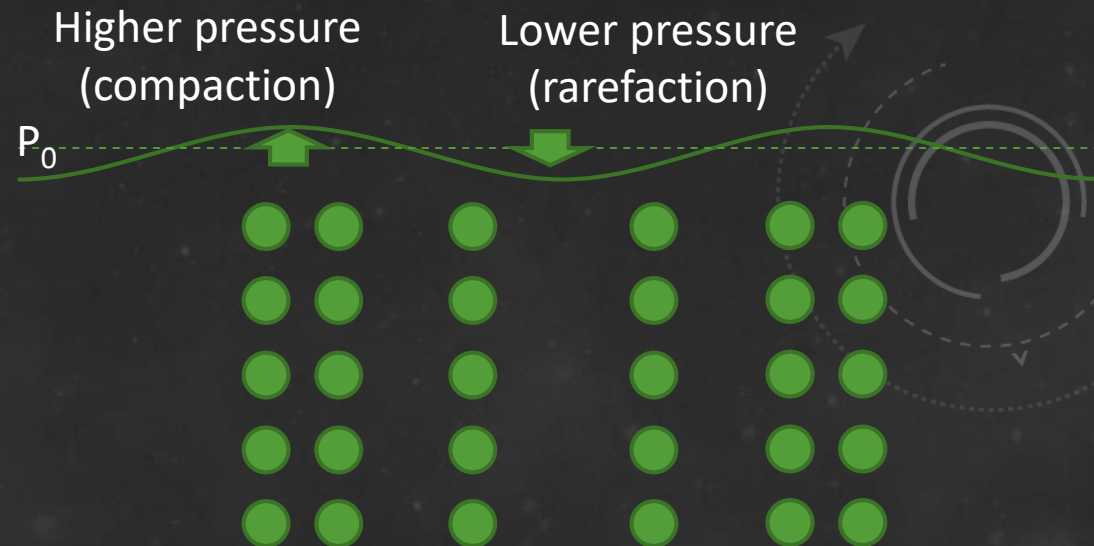
Imagine **air particles** in a room at a standard pressure (P_0)

- Air particles aren't connected to each other like the particles in a string. They can only affect each other by **colliding** into each other.
- This means that to produce sound in air, one has to cause particles to alternately **compress** (increasing their pressure) and **rebound** (reducing their pressure).
- Because the particles are moving **back and forth in the direction of the wave**, sound waves are **longitudinal**.



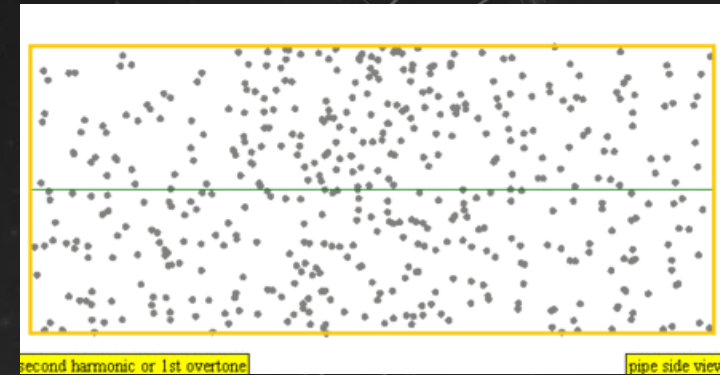
It is hard to see wave properties because we can't see the air. We can, however, visualize the **pressure changes** as a sinusoidal wave:

- **wavelength** (distance between compressions)
- **amplitude** (maximum pressure difference).



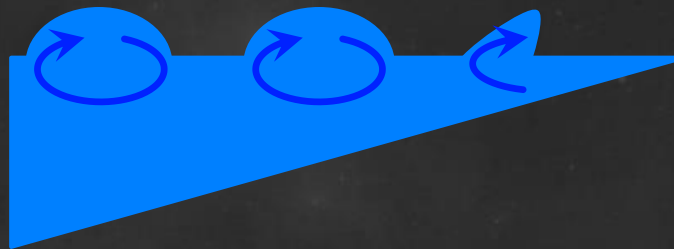
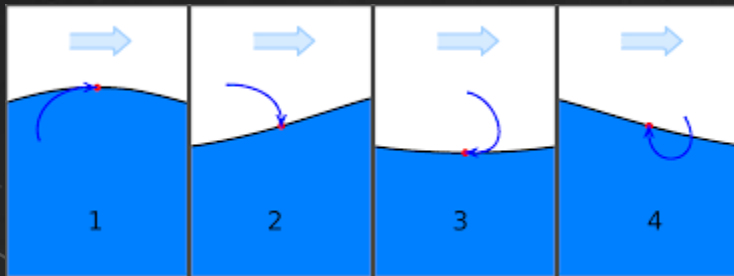
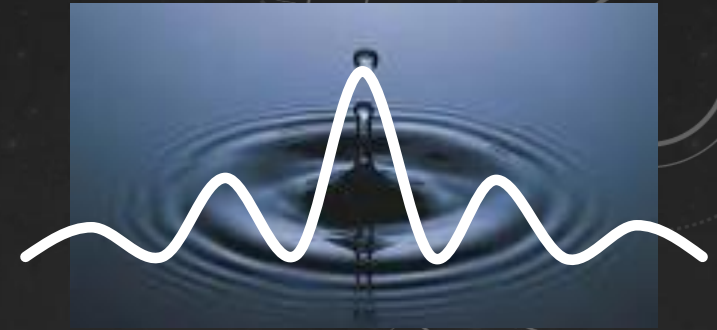
SOUND WAVES

- Waves can travel via **longitudinal** motion (**pressure waves**) through **gases** like air, but also through **solids** and **liquids**.
- **Transverse waves** can **only** travel through a **solid** since the particles move perpendicular to the wave, and so must be attached to the other particles in order to affect them.
- The speed of the pressure wave through a material is what we call the **speed of sound** in that material.
 - The speed of sound in **air** is **343 m/s** (at room temp).
 - In **water** sound travels at **1500 m/s**.
 - Sound waves travel **6100 m/s** in **steel**.
- The **speed of sound** in air also depends on the air's **temperature** and its **density**.
- The **frequency** of a sound wave is interpreted by our ears and brain as a **pitch**.



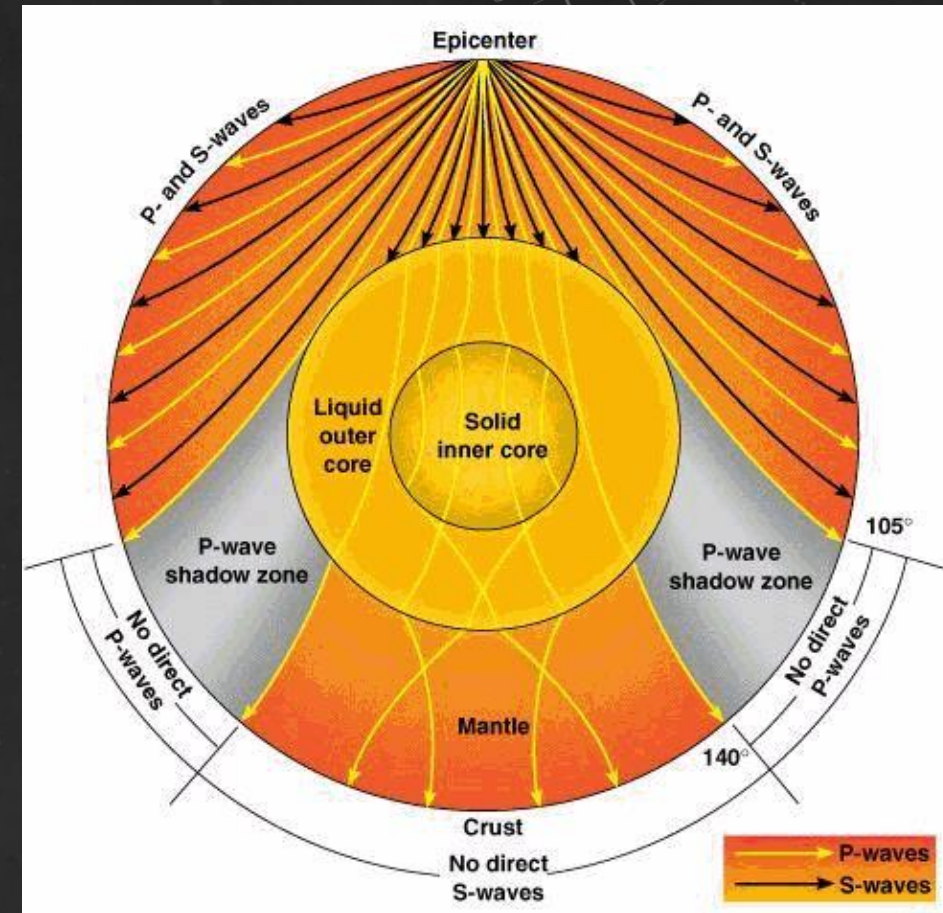
APPLICATION: OCEAN SURFACE WAVES

- In shallow water, **surface waves** (ripples) are mostly **transverse waves**.
- In **deeper water**, surface waves combine with longitudinal waves just under the surface to cause **circular motions**.
- As the waves approach the shore, the circular motion is **interrupted** by the beach. The back of the circular wave continues on, forming the **crashing wave**.



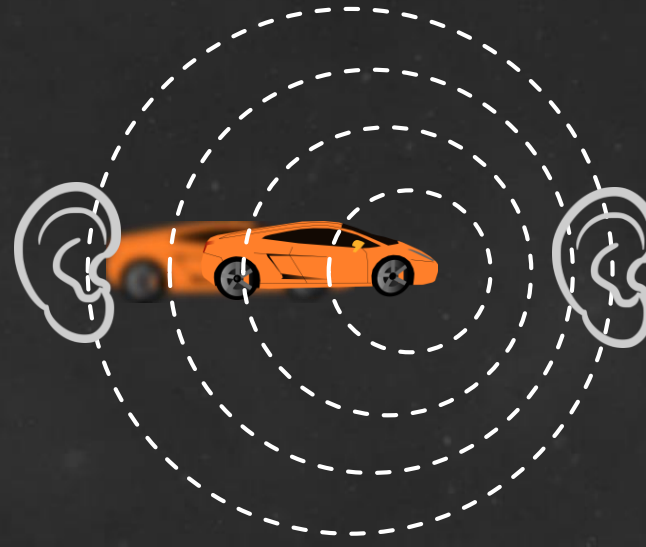
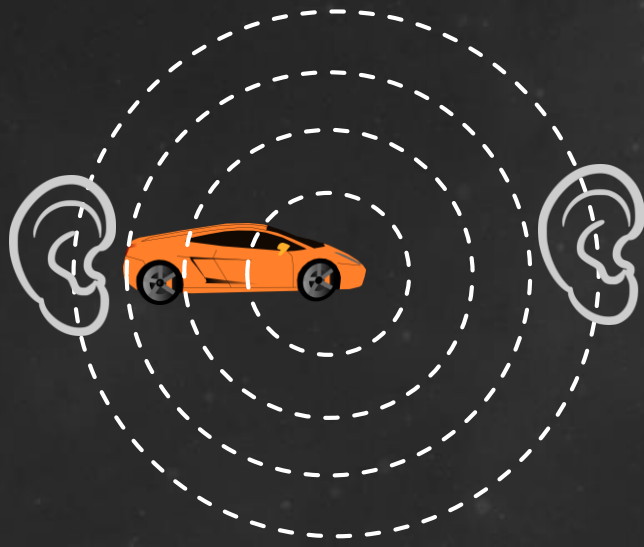
APPLICATION: EARTHQUAKES

- **Earthquakes** generate both **longitudinal** and **transverse** waves.
 - Longitudinal, or pressure, waves are called **P-waves**.
 - Transverse waves are called **S-waves**.
 - The waves travel in curved paths due to the changing density of the layers of Earth.
- Transverse waves (**S-Waves**) **can't pass through the liquid core**, and so aren't detected on the other side.
- Longitudinal waves (**P-Waves**) **do pass through the liquid core**.
- Together, the paths of the waves provide information about the interior of Earth.



APPLICATION: DETECTING SPEED WITH DOPPLER SHIFT

- **Stationary car:** The horn sounds the same to observers in front and behind. The sound waves reach the ears at the **same frequency**.
- **Moving car:** The sound waves are more **closely spaced in front**. The car catches up to the previous wave before generating a new one.
 - The sound waves reach the observer in front with a **greater frequency**, which is interpreted as a **higher pitch**.
 - The observer **behind the car** receives waves at a **lower frequency**, and hears a **lower pitch**.



CONCLUSION

- **Mechanical waves** are **displacements** within a **physical medium**.
- If the particles of the medium travel...
 - ...**perpendicular** to the wave, then it is a **transverse** wave. (Example: wave in a string)
 - ...**parallel** to the wave, then it is a **longitudinal** wave. (Example: sound wave)
- Disturbances can be **pulses**, **periodic waves**, or **sinusoidal waves**.
- **Periodic waves** can be characterized by their **period**, **frequency**, **wavelength**, and **amplitude**.
- **Sound waves** are a series of **compressions** and **rarefactions** in the air. Sound travels at different speeds through different materials, but is **fastest in solids** and **slowest in gases**.
- Other applications of mechanical waves are **ocean waves**, **earthquakes**, and the **Doppler effect**.
 - The Doppler effect shifts the perceived frequency of waves from a source. For a source traveling **toward** the observer, it is a **higher pitch**, and for a source travelling **away**, it is a **lower pitch**.

Image attributions:

Molecular motion: <https://en.wikipedia.org/wiki/Harmonic>

Tuning fork: <https://dir.indiamart.com/impcat/tuning-forks.html>

Standing Waves – sound: https://www.nhn.ou.edu/~jeffery/astro/waves/standing_waves_sound.html

Wave photo: <http://photographyblogger.net/12-impressive-pictures-of-waves/>

Wave dynamics: https://en.wikipedia.org/wiki/Wind_wave

Water drop: <http://www.warrenphotographic.co.uk/02843-water-drop-forming-spike>