Waves (Chapter 15)

Waves are **everywhere:**

- atmosphere (acoustic) - oceans (tides)
- land (seismic) - space (radiation)

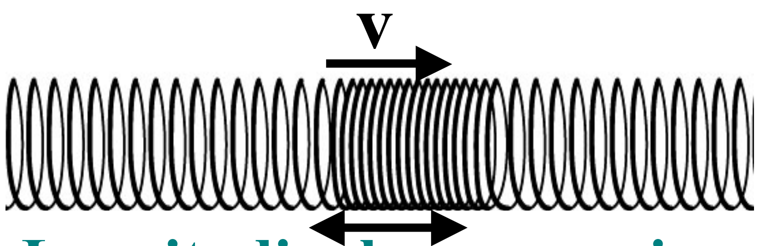
- Waves are **very important mechanism** for the **transport** of **energy**.
- Wave motions have implications in **all** areas of physics: an enormous range of phenomena can be explained in terms of waves, from quantum mechanics to tsunamis!

So what is a wave?

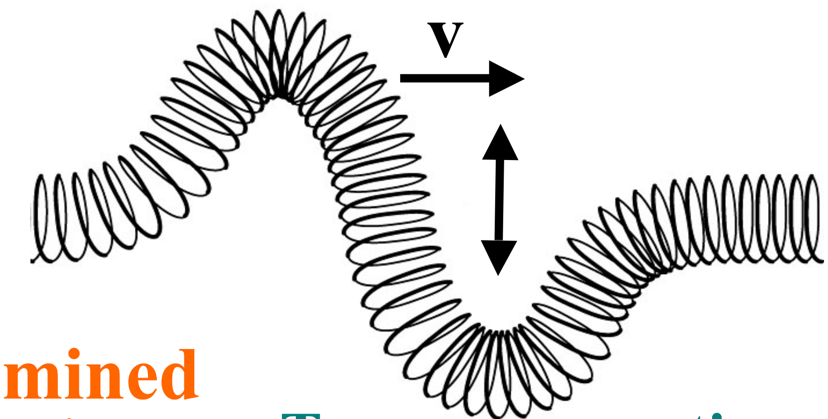
Fundamental question: As waves **move** towards the **shore**, why is there **no buildup** of **water** on the beach?

- **Result:** A wave is a **disturbance** that **moves** within a **medium**. (but the medium itself **stays put**!)
- A wave can consist of a **single "pulse"** or a **series** of **periodic pulses**.

- The **wave disturbance** can be in the form of a:



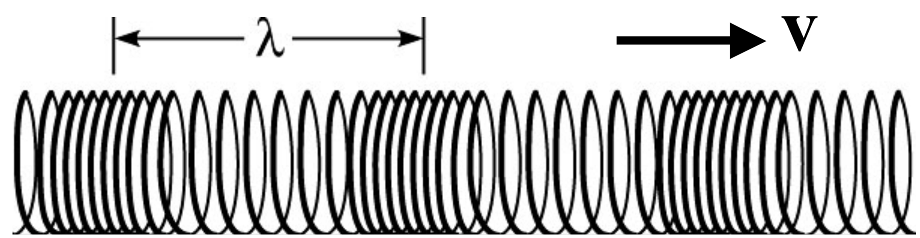
Longitudinal compression



Transverse motion

- **Velocity** of the 'pulse' is **determined** by the **medium** it is propagating in.
- The **wave acts** to **transmit energy** through the **medium**… (shore line erosion).

Periodic waves:



- A periodic wave consists of a **series** of **pulses** at **regular** (equal) **time intervals**.
- Time between the pulses is called the wave period (T).
- **Frequency** of wave is **number of pulses per second**:

$$f = \frac{1}{T} \quad \text{(Units Hertz, Hz)}$$

- **Separation** of the **pulses** is called the **wavelength** (**λ**).
- Thus for a **periodic disturbance**, the **velocity** is **equal** to **one wavelength** (i.e. distance between two successful pulses) **divided** by **one period** (i.e. time between the pulses).

$$v = \frac{\lambda}{T} \quad \text{or} \quad v = \lambda . f$$

- This is valid for **any periodic wave** (sound, light, etc) and relates the **velocity** to **wavelength** and **frequency**.
- The wave **velocity depends** on the properties of the **<u>medium</u>** (e.g. air, water, ground) and is often known.
- The **wave frequency** is a **property** of the **wave source** (e.g. speech).
- As the **frequency varies**, the **wavelength changes:**

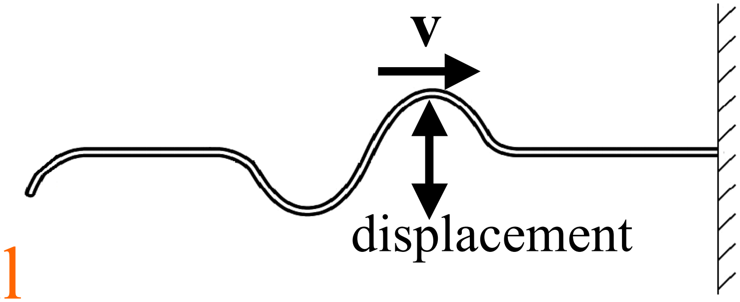
$$v = \lambda . f$$

$$\lambda \downarrow \quad f \uparrow$$

… to keep **<u>velocity constant</u>**.

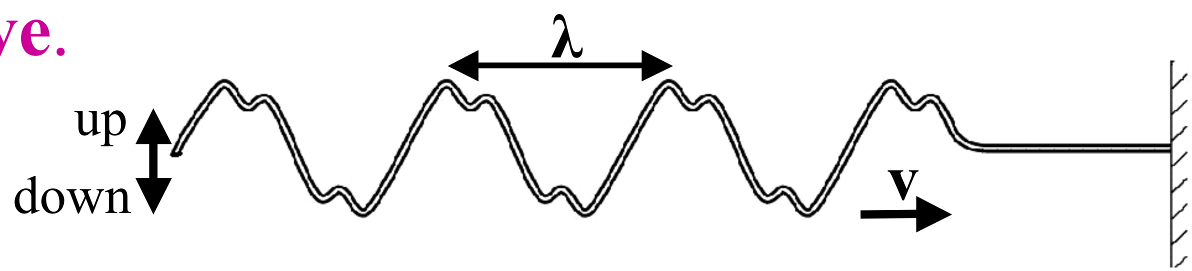
Example: Waves on a Rope

- By moving **free end up** and **down** we can generate a **transverse** wave ‘**pulse**’.



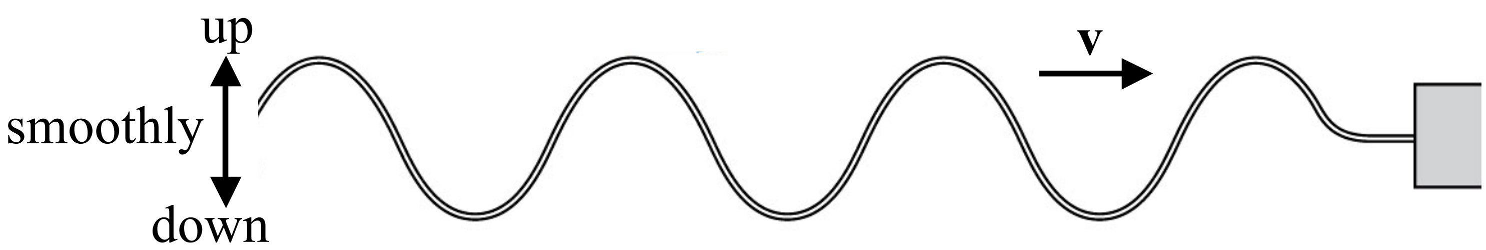
  Pulse **propagates** down rope to wall **creating** an **instantaneous vertical displacement**.

- A series of ‘**snap-shots**’ would show the **wave moving** down rope at **constant speed** ‘v’.
- If we **repeat** up /down motion **regularly** you can make a **periodic wave**.



- A **periodic wave** can have a **complex shape** depending on the **perturbation induced**.
- When the **wave reaches** the **wall,** it is **reflected back** along rope and then **interferes** with the **forward** moving **wave** creating a **more complex** wave **pattern**.

Simple Harmonic Wave (Pure Sinusoid)

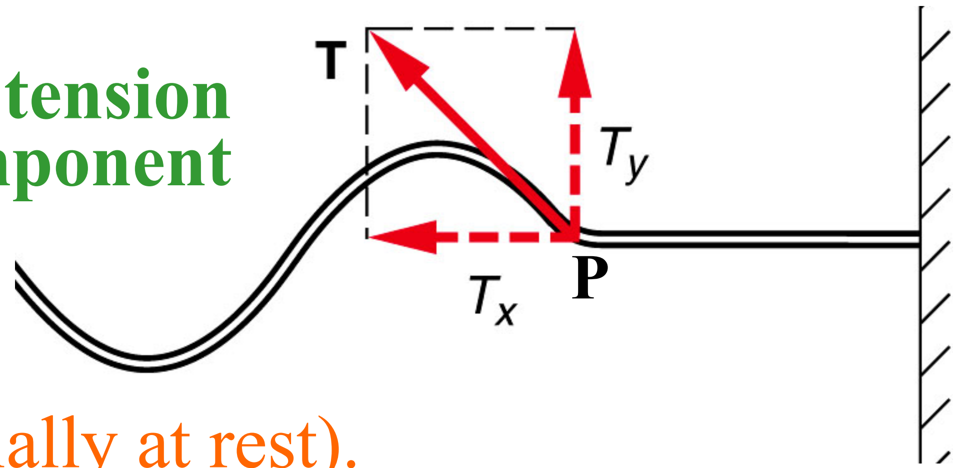


- When we move rope end up and down very **smoothly** and **regularly**, we create a **sinusoidal variation** called a "**harmonic wave**".
- **Harmonic waves** are **easy to create** as the individual "**elements**" in a **rope** act like a **spring** which is a **natural harmonic oscillator** (Force α – displacement).
- **Harmonic waves** are very **important** for **everyday wave analysis** as any **complex periodic** wave **motion** can be **broken down** into a **sum** of pure **harmonic waves**.
- **Fourier analysis** – uses harmonic waves as building blocks for complex everyday wave motions (e.g. speech).

Why does the pulse move?

- Experiments show **velocity** is **independent** of wave **shape**.

- **Lifting** the rope causes the **tension** in it to gain an **upward component** of motion.



- This **upward force** acts on **element** of rope to **right** of point ‘P’ (which was initially at rest).
- This causes the **next element** to **accelerate upwards** and so on down the rope.
- **Velocity of pulse** (wave) depends on how **fast** the **individual elements respond** to the initial **perturbation** (i.e. on how fast they can be **accelerated** by the **tension force**).

$$v = \sqrt{\frac{T}{\mu}} \qquad \text{where } \mu = \frac{\text{mass of rope}}{\text{length}}$$

Result (for a rope):

- **Larger tension** => **higher** wave **velocity.**
- **Heavier rope** (μ larger) => **slower** wave **speed**.

Example: A rope of length 12 m and total mass 1.2 kg has a tension of 90 N. An oscillation of 5 Hz is induced. Determine velocity of wave and wavelength.

L = 12 m
m = 1.2 kg
T = 90 N

1) First we need to calculate μ:

$$\mu = \frac{m}{L} = \frac{1.2}{12} = 0.1\,\text{kg/m}$$

2) now velocity:

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{90}{0.1}} = \sqrt{900} = 30\,\text{m/s}$$

3) and wavelength:

$$v = f.\lambda \quad \text{or} \quad \lambda = \frac{v}{f}$$

$$\lambda = \frac{30}{5} = 6\text{ m}$$

Speed of Sound

- As with the speed of a wave on a rope, the speed of sound depends on the **medium** it is propagating through.
- In air, at room temperature the speed of sound (at sea level) is approximately 340 m/s. (750 mph)
- The factors that determine speed of sound are related to how rapidly one molecule can transmit **changes in velocity** to another molecule to propagate the wave.
- In air (gases) **temperature** is a major factor as molecules have higher K.E. (ie velocities) at higher temperature.
  - eg. An increase of 10 K (10C) increases speed by ~ 6m/s. (and vice versa).
- For other gases the **mass** of molecules is important.
  - eg., hydrogen molecules are light and easier to accelerate and speed of sound is about 4 times higher than in air (for similar pressure and temperature).

Comparison of Speed of Sound

Medium	Speed
Air	~340 m/s
Water	4-5 times air speed ~1400 m/s
Metal/rock	15-20 times air speed, ~ 6000 m/s

- Speed of sound in liquids and solids is much higher as molecules much closer together.

Example: lighting vs. thunder

- Lighting flash reaches you almost instantaneously but sound travels at **340 m/s.**
- Rules: 1 km takes ~ 3 s (1 mile ~ 5 s)
- By counting seconds between flash and thunder can tell how far storm is away.

Frequency of Sound Waves:

- Frequency range of human hearing is ~ 20 Hz to 20,000 Hz.

frequencies

below → **infrasonic**

above → **ultrasonic**

- Ultrasound and infrasound occur commonly in nature but are outside our hearing range.
- Bats, dolphins use ultrasound for echo location.
- Ultrasound used to image babies in womb.
- Whales produce powerful infrasonic calls that can be "heard" over distances of several thousand kilometers.
- Large meteors burning up in atmosphere emit infrasonic waves.