U4:L1 Transverse + Longitudinal Waves

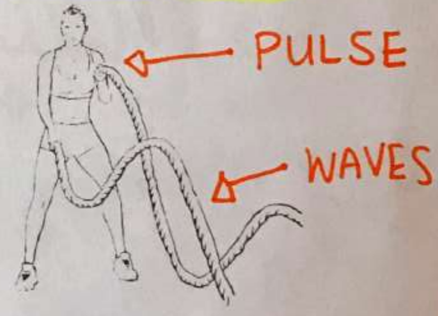
Most of us have seen what happens when a raindrop or a stone strikes the surface of water. A circular wave forms and moves outward. On a calm day, it is important to realize that the waves are not carrying water to the shore. The wave may move with a velocity to the shore, but the particles of water do not move to the shore.

If there is a leaf on the water surface, you can see that the leaf moves up and down but it does not move towards the shore or away from the shore. In this example, the water is the medium through which the wave moves. The water has limited movement but the wave can travel a long distance. The wave itself is not matter but the wave pattern can travel through matter. A wave thus consists of oscillations that move without carrying matter with them.

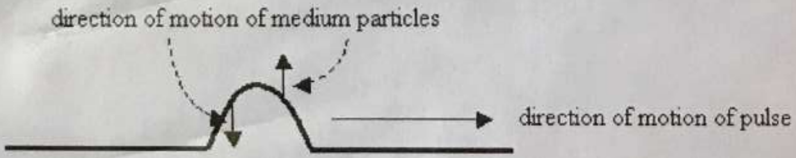
Although waves do not carry matter from one place to another, they do carry energy. For example, when a rock is thrown into the water, some of the energy of the moving rock is transferred to the wave. The moving air particles in wind can also give energy to the water wave. A hand moving a rope or a slinky up and down is transferring energy to it. This energy moves down the rope and can be transferred to an object at the other end. All forms of waves transport energy.

The scientific definition of a **wave** is a **disturbance that transfers energy from one place to another.**

A single pulse can be produced on a rope or slinky by a quick up-and-down motion of the hand. The hand pulls up on one end of the rope and this causes the next particles to move upward since they are attached. As each next piece of rope moves upward, the **wave crest moves outward along the rope**. A short time later, the end piece of the rope has been returned to its original position by the hand. Each of the next pieces of rope are also pulled back down again after reaching the peak position.



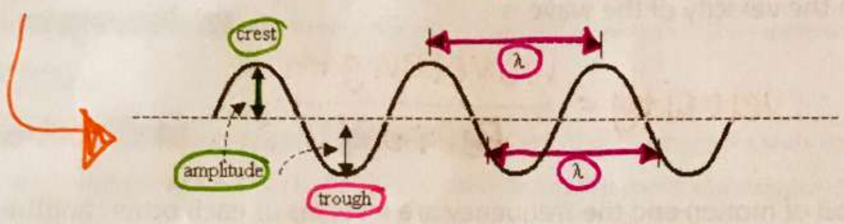
- A **disturbance is the source of a pulse.**
- Forces between pieces of the rope cause the **pulse to travel outward.**



A **continuous** or **periodic wave** is produced by a disturbance that is moving back and forth continuously (non-stop).

A **transverse wave** is a moving **wave** whose oscillations are **perpendicular** to the direction of the **wave** or path of pulse. Examples of transverse waves are waves caused by a hand oscillating a rope, light waves and waves travelling on the strings of instruments such as guitars.

The diagram below shows a **transverse periodic wave.**



$f = 3$

The high points on a wave are called **crests.**

The low points are called **troughs.**

The **amplitude** (A) is the maximum height of a crest or the depth of a trough relative to the particle's undisturbed position. (This undisturbed position is the dashed line in the diagram above and is sometimes referred to as the equilibrium level.) Note that the total distance from crest to trough is twice the amplitude.

One **cycle** of a wave is one complete oscillation. In the case of a transverse wave, it is one complete up and down movement.

The **wavelength** is the horizontal length of one cycle of the wave. It can also be described as the horizontal distance between two successive crests, two successive troughs, or any successive equivalent points on the wave. The Greek letter lambda (λ) is used as a symbol for wavelength.

The **frequency** (f) is the number of complete cycles (or crests) that pass a given point per unit of time. It is commonly measured in cycles per second or hertz (Hz).

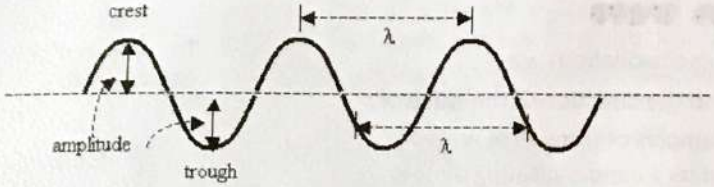
The **period** (T) is the time elapsed between two successive crests passing by the same point in space. The standard unit of period is the second. It is the time for one cycle or wavelength of a wave to pass a point. The period is therefore the inverse of the frequency:

$T = 1/f$

∴ In above situation

$$T = \frac{1}{f} = \frac{1}{3} = 0.\overline{33}\,s$$

The **wave velocity** (v) is the velocity at which the wave moves.



To make it easier to visualize, let us focus on a wave crest moving to the right. If the crest travels a distance of one wavelength, λ, to the right in a time of one period, T, then the velocity of the wave is

$$\boxed{v=\frac{\lambda}{T}}$$

velocity = $\frac{\text{wavelength}}{\text{Period}}$

Since the period of motion and the frequency are inverses of each other, another way to determine the speed of the wave is

$$\boxed{v=f\lambda}$$

velocity = (frequency) × (wavelength)

EX: For example, suppose a wave has a wavelength of 5.0 m, and that it takes 0.20 s for one wavelength to pass a given point. Then in this case, $\lambda = 5.0$ m, $T = 0.20$ s, and

$$\boxed{v=\frac{\lambda}{T}}=\frac{5.0\,m}{0.20\,s}=25\text{ m/s}$$

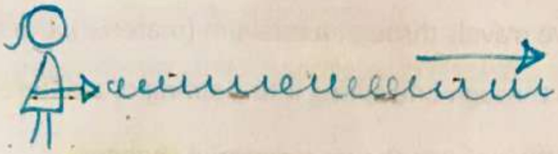
The frequency for this wave is

$$\boxed{f=\frac{1}{T}}=\frac{1}{0.20\,s}=5.0\text{ Hz}$$

If we use this frequency to determine the speed of the wave, we see that

$$\boxed{v=f\lambda}=(5.0\text{ Hz})(5.0\text{ m})=25\text{ m/s}$$

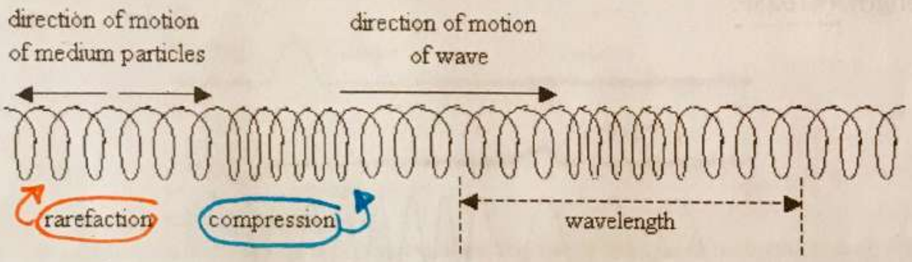
In a **longitudinal wave**, the vibration of the particles of the medium is along the same direction as the motion of the wave.



These kinds of waves can be formed on a slinky by alternately compressing or expanding one end. A series of compressions and expansions can then propagate along the spring.

The **compressions** are those areas in a longitudinal wave that are momentarily close together.

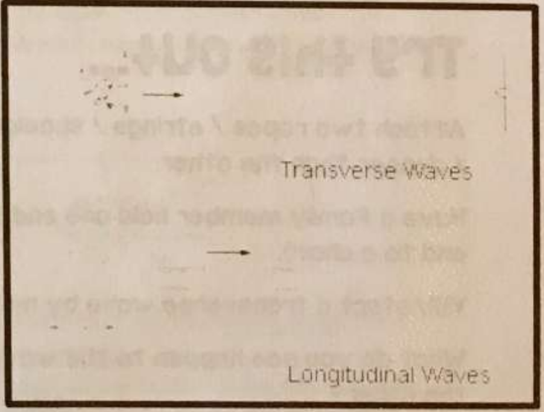
Rarefactions (also called **expansions**) are regions where the coils are momentarily far apart. Compressions and rarefactions correspond to the crests and troughs of a transverse wave.



Longitudinal waves also have a wavelength. The diagram above shows one possible way to show a wavelength. It is drawn from the center of a rarefaction to the center of the next rarefaction. But it can also be described as the horizontal distance between any successive equivalent points on the wave.

Frequency and wave velocity have the similar meanings for the longitudinal wave as they do for the transverse wave.

An example of a longitudinal wave is a sound wave travelling through the air. A vibrating object such as a tuning fork or your vocal cords alternately compresses and rarefies the air and produces a longitudinal wave that travels outward in the air.



U4:L2 Waves Interacting

Waves Moving from one Material to Another

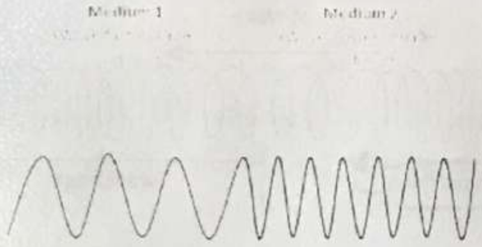
When a pulse or wave travels through a medium (material), the speed is constant.

When a wave moves through one spring into a spring of a different material:

- the speed of the wave in the new material changes.
- The frequency of the wave does not change since this is constant once the wave has been generated at the source.
- If the frequency of the wave is constant, and the speed of the waves changes in the new material, then the wavelength also changes.

So, if a wave travels from a light rope to a heavy rope, the wave slows down and the wavelength decreases.

But if the wave travels from a heavy rope to a light rope, both the speed and the wavelength increase.



These properties are true of all waves. When the medium changes, so does the speed and the wavelength.

Try this out...

Attach two ropes / strings / shoelaces/ etc. together. Make sure one is thicker / denser than the other.

Have a family member hold one end while you hold the other (or tie the other end to a chair).

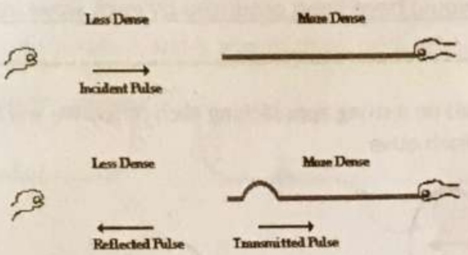
YOU start a transverse wave by moving your end up and down.

What do you see happen to the wave as it moves from one of the materials to the other?

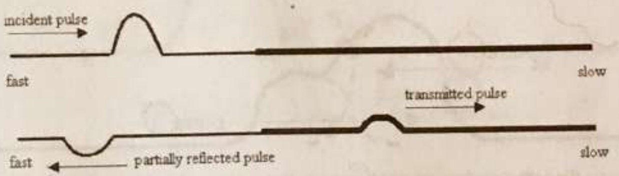
Wave Reflection from One Medium to Another

When a wave moves from one medium to another, some reflection occurs at the boundary between the two media/materials. This is called **partial reflection** because some of the energy is transmitted into the new medium and some is reflected back into the original medium.

- For waves undergoing reflection, there is no change in the speed, wavelength, or frequency.

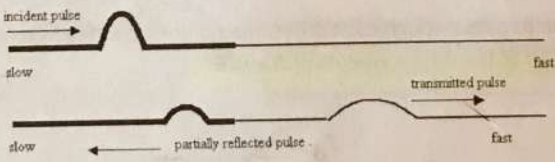


When a wave passes from a fast medium into a slow medium (light spring to heavy spring), the particles in the slower medium have greater inertia. This second medium acts like a rigid obstacle, and the reflected wave is inverted. The transmitted wave is not inverted.



- Moving from a fast medium to a slow medium, the transmitted wave is moving slower, has a shorter wavelength, and is transmitted so that it is not inverted.
- The partially reflected wave is moving at the same speed as the incident pulse, has the same wavelength, has a smaller amplitude, and is inverted.

When a wave travels from a slow medium to a fast medium, the fast medium acts like a **free-end** reflection. No inversion occurs in either the partially reflected or transmitted waves. But the wavelength is longer.



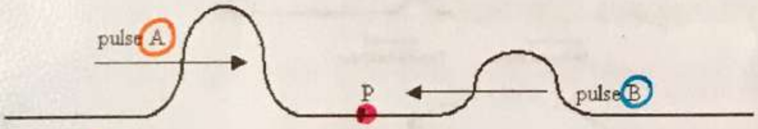
- Moving from a slow medium to a fast medium, the transmitted wave is moving faster, has a longer wavelength, and is transmitted so that it is not inverted.
- The partially reflected wave is moving at the same speed as the incident pulse, has the same wavelength, has a smaller amplitude, and is not inverted.

Constructive Interference

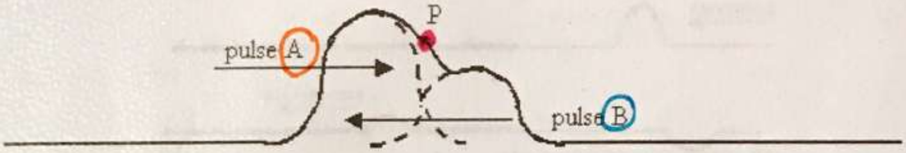
Wave interference occurs when two or more waves act at the same time on the same particles of a medium resulting in a new displacement.

To determine the new displacement of the particles, we use the **Principle of Superposition** which states that the resultant displacement of a given particle is equal to the sum of the displacements that would have been produced by each wave independently.

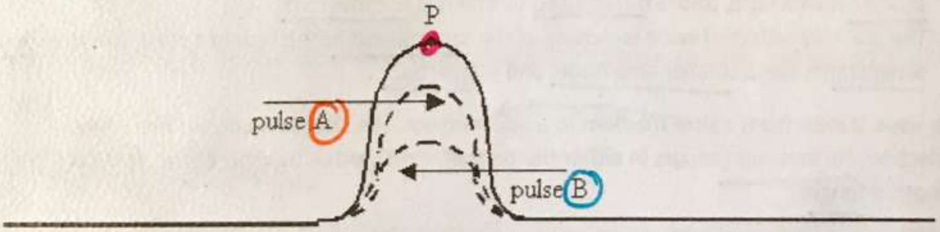
The diagram below shows two pulses on a string approaching each other. We will follow the motion of point P as the pulses pass through each other.



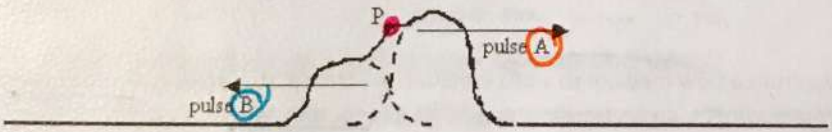
The amplitude of pulse A is 5 mm and the amplitude of pulse B is 3 mm. At a later moment in time, the pulses begin to interact with each other as shown below. At the moment shown, the point P has been moved up upward 2 mm by pulse A and 2 mm by pulse B.



When the two pulses are directly on top of each other, the new pulse has a maximum amplitude of 8 mm which is the sum of the amplitudes pulses A and B.



As the two pulses continue to pass through each other, the point P now begins to descend. The vertical displacement of P is the sum of the displacements of A and B.

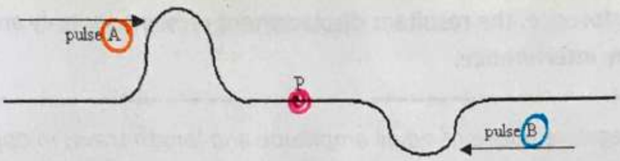


Deconstructive Interference

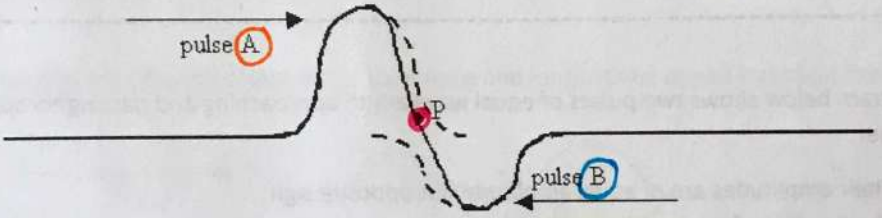
In the previous section, we saw an example of two waves interfering to produce a resultant displacement **greater** than the displacement that would be caused by either wave. This kind of interference is called constructive interference.

Deconstructive Interference occurs when the resultant displacement is **smaller** than the displacement caused by one wave.

The diagram below shows pulses A and B approaching each other as shown.



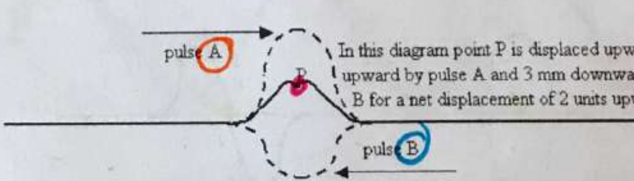
The series of diagrams shows what happens to the point P as pulses A and B interfere with each other.



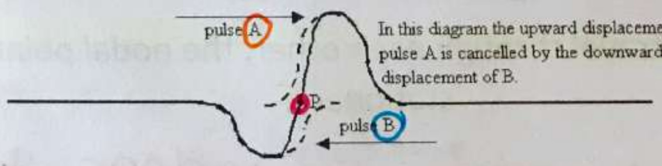
At the moment shown, pulse A displaces point P upward 2 mm and pulse B displaces the point downward by 1 mm. The resultant displacement of the pulse is 1 mm upward.

Note that in the areas of the medium where interference does not occur, the position of the particles in the medium (represented by the solid line) is that created by each individual wave. In the diagram below the pulses are directly on top of each other.

The final diagram shows the pulses after they have nearly completely passed through each other.



In this diagram point P is displaced upward 5 units upward by pulse A and 3 mm downward by pulse B for a net displacement of 2 units upward.



In this diagram the upward displacement by pulse A is cancelled by the downward displacement of B.

Standing Waves

When waves interfere with each other, their amplitudes and wavelengths are often different. If conditions can be controlled so that the waves have the same amplitude and wavelength but travel in opposite directions, the resultant interference pattern is particularly interesting.

A **standing wave** can be defined as the resultant of two wave trains of the same wavelength, frequency, and amplitude travelling in opposite directions through the same medium.

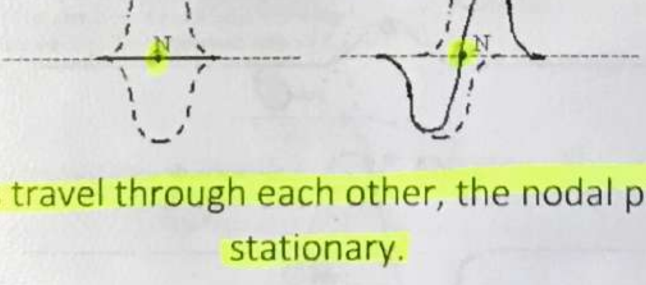
In most cases of interference, the resultant displacement remains for only an instant, making it difficult to analyze the interference.

When positive and negative pulses of equal amplitude and length travel in opposite directions and interfere, there is a point that remains at rest throughout the interference of the pulses.

This point is called a **node** or a **nodal point** and the letter "N" is used to designate this point.

The diagram below shows two pulses of equal wavelength approaching and passing through each other.

- Their amplitudes are of equal amplitude but opposite sign.
- The location of the nodal point is shown.
- At each of the moments, the upward displacement is cancelled by the downward displacement to produce the node.



As the pulses travel through each other, the nodal point remains stationary.

★ Make sure to watch the videos - they help!