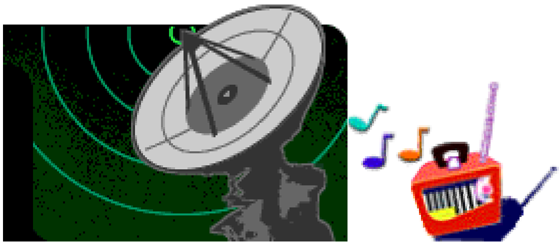
UNDULATORY PHENOMENA



The antenna emits electromagnetic waves that your radio turns into sound waves.

Undulatory phenomena are part of the world around us. Sounds reach us by means of waves, we perceive light as waves; you could say that it is through waves that we get almost all the information that we possess.

By analysing undulatory phenomena as simple as waves extending across a puddle or the peaks and troughs propagated along a shaking rope, we will try to study the general characteristics of all undulatory movements.

By clicking on the Forward link, you will be able to find out the objectives of the unit in detail.

Objectives in the study of undulatory motion

- To identify a simple harmonic vibration.
- To identify the different types of undulatory motion.
- To understand and be able to relate the different magnitudes of undulatory motion with each other.
- To understand and be able to explain qualitatively the characteristic phenomena of waves like interference, diffraction, reflection and refraction.
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- To understand the undulatory nature of light and sound.

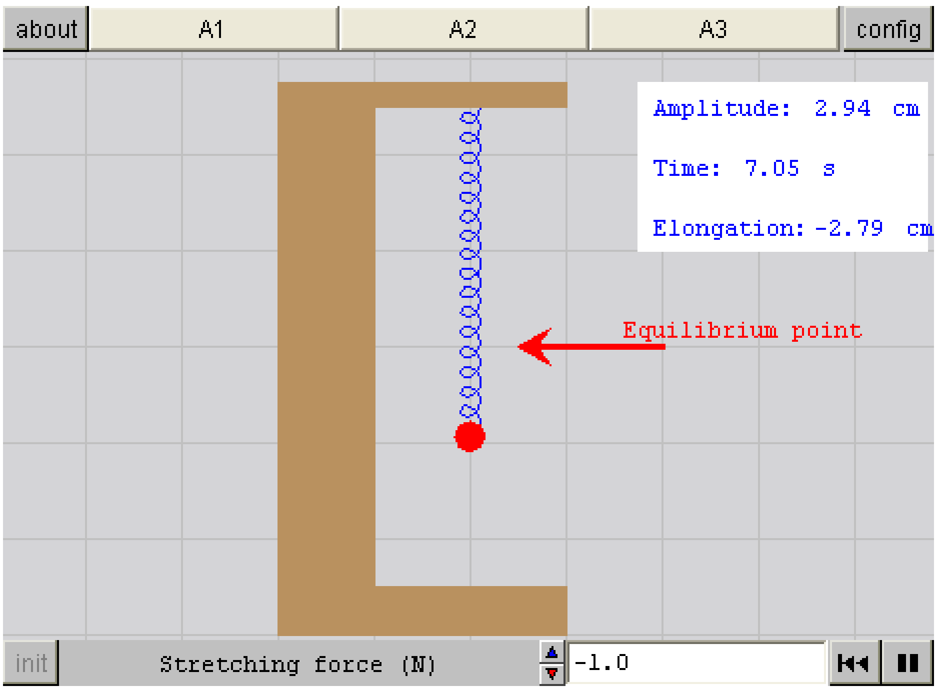
1.1 Definition of a harmonic vibration

All undulatory phenomena are characterized by their transmission of some type of vibration. It is therefore logical to study vibrations first, especially harmonic vibrations.

A particle which oscillates around a point of equilibrium, subject to a force proportional to the distance to this point, has a **simple harmonic vibratory movement**.

A spring which is made to vibrate by a force which keeps it from equilibrium is a good example. You can study its movement in the following visual.

You can stretch the spring with the help of your mouse:

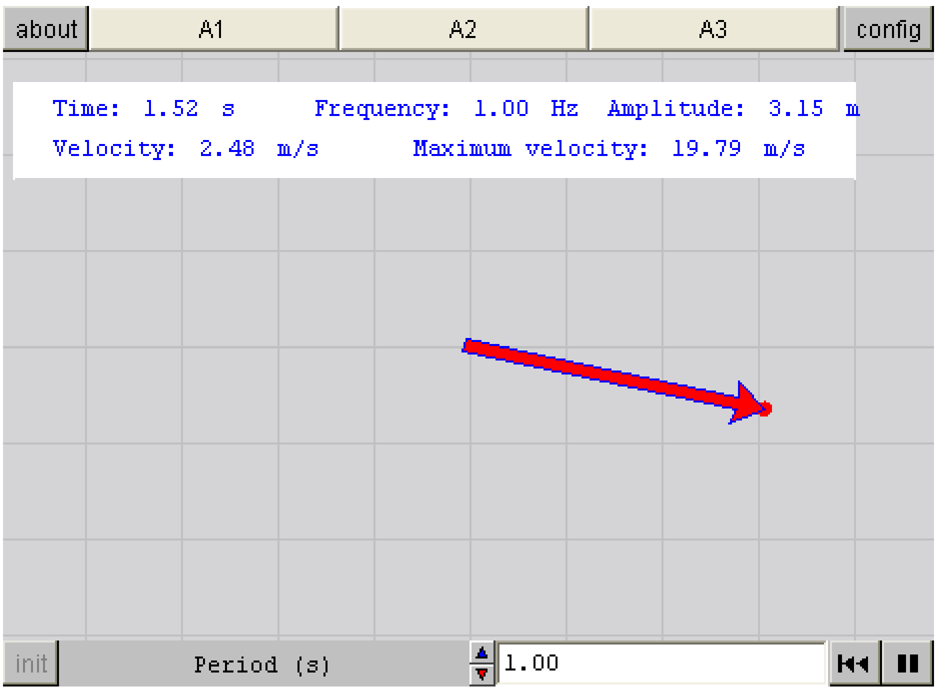


1.1 Important magnitudes in a vibration

In the world around us we can find many examples very similar to harmonic vibrations: a point on the string of a guitar after plucking it, the tremor at the end of a sheet of metal when it is struck... In all of these there are **common characteristic magnitudes**. These magnitudes are going to play an important role in our understanding of waves.

In the following visual we will try to study them, not with a spring or a similar example, but with a particle subject to a harmonic vibration for causes which are not of interest at the moment. We are just interested in knowing the magnitudes which describe this movement and some relations among them.

By dragging the end of the vector with your mouse you can change the direction of the vibration and its amplitude.



1.2 Conclusions from studying harmonic vibrations

A harmonic vibration is produced when a particle oscillates around a point of equilibrium, so that its velocity is maximum when it passes through the point of equilibrium and nil at the ends of the oscillation.

In all harmonic vibrations the following magnitudes are important:

Elongation	The distance to the point of equilibrium
Amplitude	The maximum value of the elongation
Period	The time taken by the particle to complete an oscillation
Frequency	The number of oscillations per unit of time. **Its value is always the inverse of the period.**

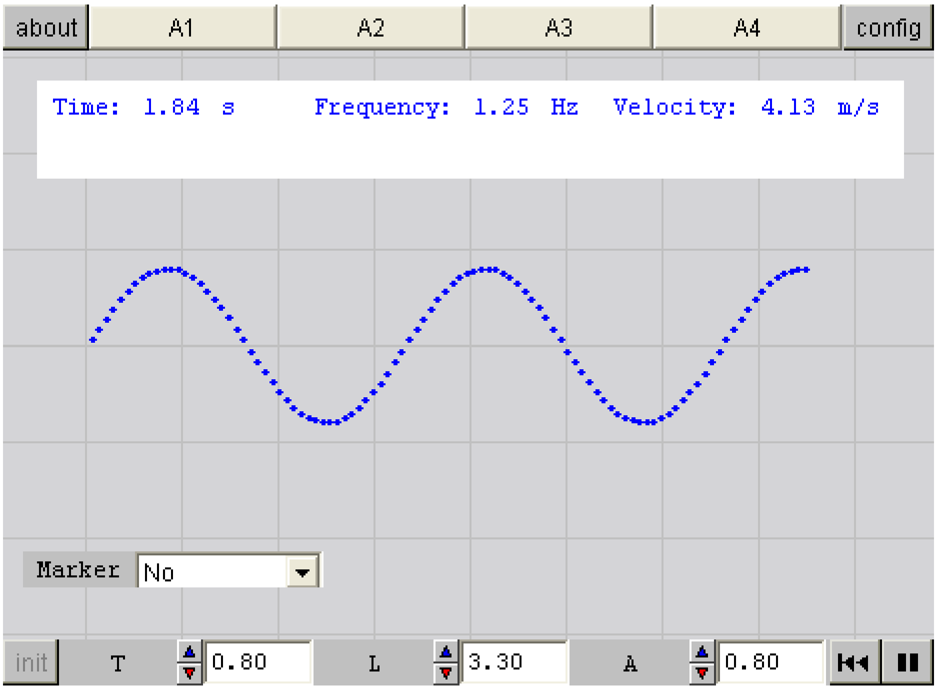
2.1 Transverse waves

We have already indicated that a **wave is the propagation of a vibration**. The transmission of disturbances along a taut rope, the waves of the sea, sound, light ... are all undulatory phenomena.

However, we should point out that not all undulatory movements are produced in the same way.

In those cases in which the vibration produced is perpendicular to the propagation of the movement, we say that we are seeing **transverse waves**. Light, for example, is a transverse undulatory phenomenon.

The easiest transverse waves to study are those of the transmission of vibrations along a taut rope. In the following visual we will study this case and try to deduce some concepts and relations of general interest.

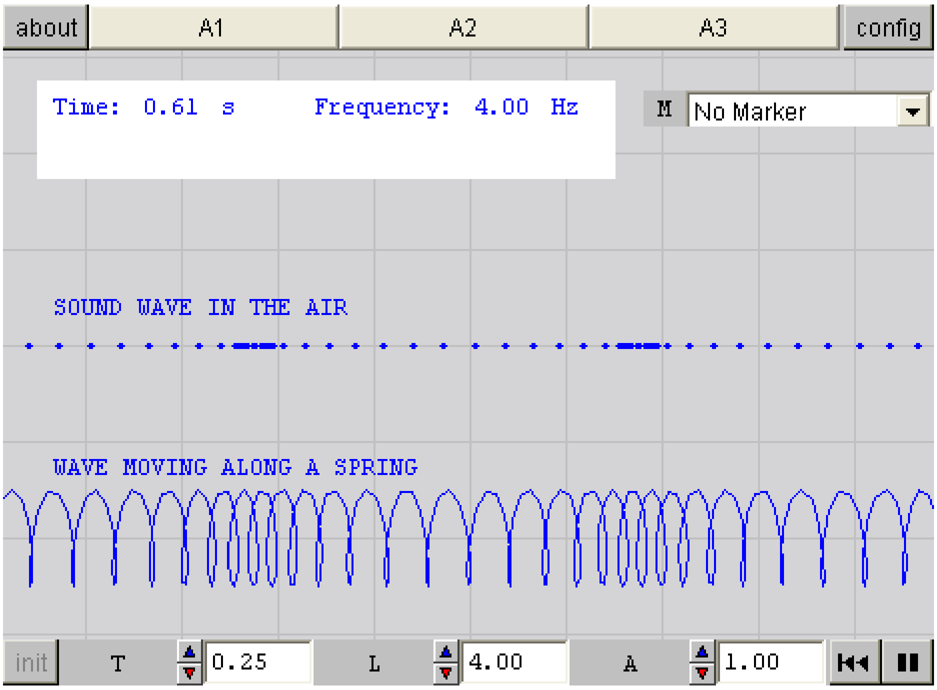


2.2 Longitudinal waves

Longitudinal waves are produced when the vibration which is transmitted and the propagation go in the same direction.

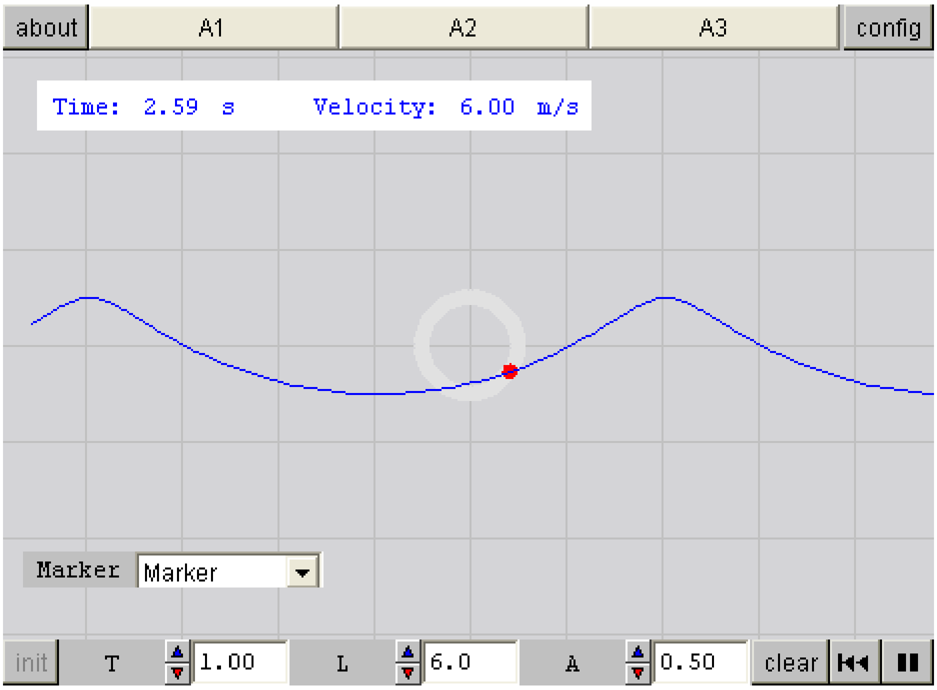
A good example of this type of phenomenon is the transmission of sound through a fluid. If you put your hand in front of your mouth as you talk you will notice how the air hits your hand when its particles vibrate in the same direction as the one in which your words are carried.

However, the easiest example to visualise is the oscillations which are transmitted along a spring. In the following visual we will study simultaneously the movement of the sound waves in the air and the transmission of longitudinal oscillations along a spring.



2.3 The waves in the sea

We have seen that there are transverse and longitudinal waves. When we observe the waves coming towards the beach, they seem to be a good example of transverse waves. However, the waves in the sea, or those that are formed on any surface of water, are a special case of undulatory movement which it is worth looking at closely. In the next two visuals we study this peculiarity.



2.4 Conclusions about the nature of waves

An undulatory movement consists in the propagation of a vibration through a medium.

If the vibration is perpendicular to the propagation, the undulatory movement is **transverse.** This is the case of light, for example.

If the vibration has the same direction as the propagation, the undulatory movement is **longitudinal**. This is the case of sound. There can be undulatory movements which are both transverse and longitudinal, like the waves on the sea.

Important magnitudes in all undulatory movements:

Period	The time taken by a wave to pass through a point. It is represented by T
Frequency	The number of waves which pass through a point each second. Its value is the inverse of the period: **f=1/T**

Amplitude	The maximum elongation of the vibration which is propagated.
Wavelength	The distance between two points of equal phase. It is represented by L
Velocity of propagation	The velocity at which the crests of the waves move. The relation is expressed as: **v =L/T** or also **v=L·f**

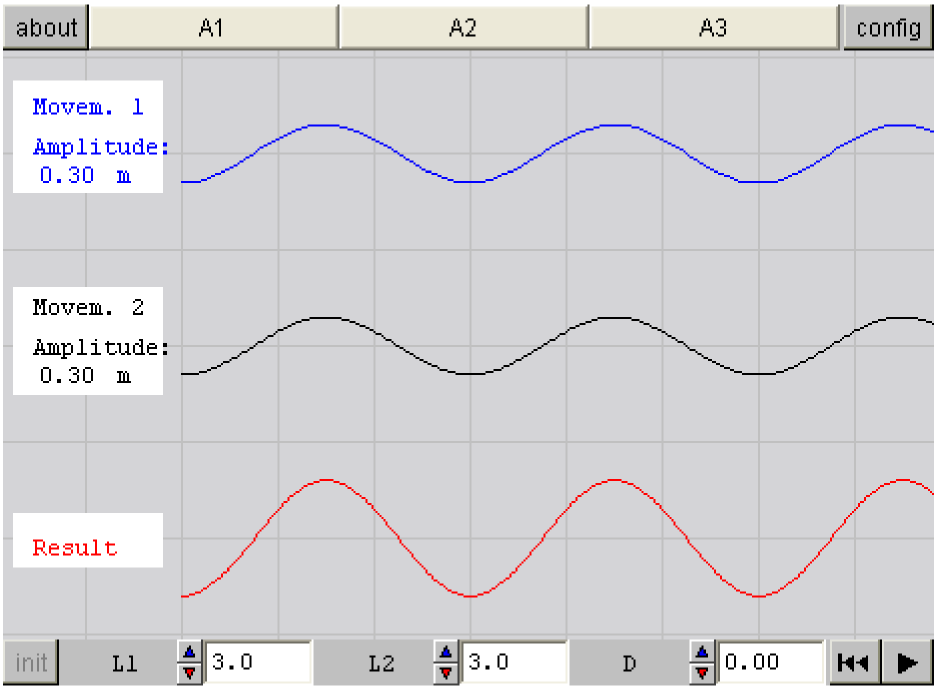
3.1 The phenomenon of interference

When two undulatory movements of equal nature cross the same region in space, their waves are superposed, in other words there is **interference**. At times you have been totally conscious of this phenomenon when you have had difficulty hearing your favourite radio station because of interference from another station.

This is because of a phenomenon which is particular to waves. When particles collide they cause mutual diversion, only waves can cross each other and continue on their way as if nothing had happened.

The easiest case of interference we can study is that which is produced in a taut rope which is shaken at two different points. We will study this in the next visual.

The visual represents the two different movements that the rope is subjected to. By clicking on play you can see the wave resulting from the superposition.



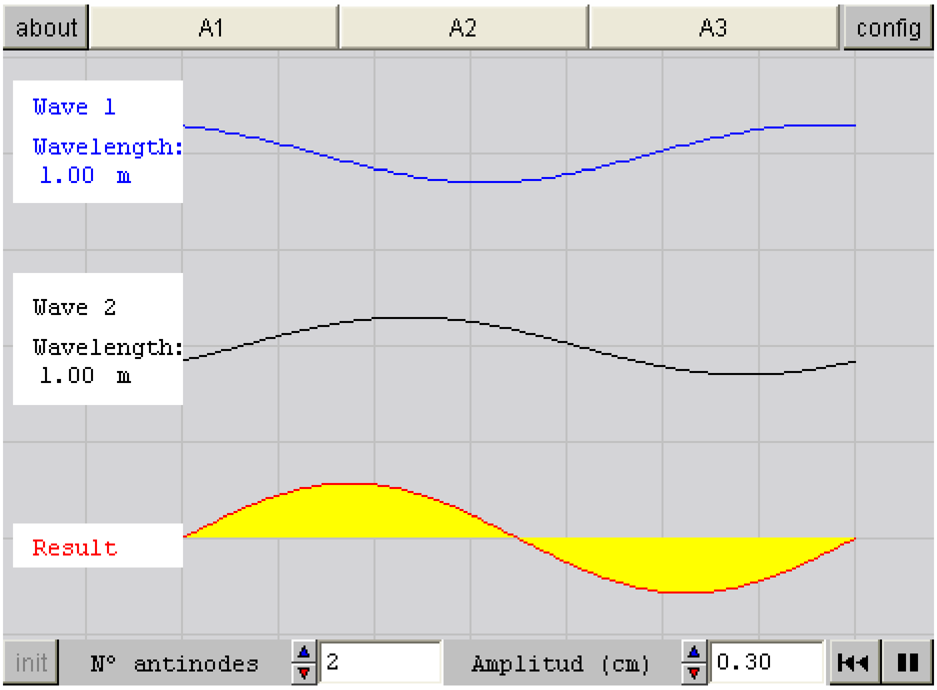
3.2 Stationary waves

When you pluck the string of a guitar, the vibration which you produce travels to both ends of the string where it is reflected. This phenomenon is repeated many times, so that what we can perceive in the string is the **superposition of two identical undulatory movements, travelling in opposite directions**.

The result of this superposition is called a **stationary wave** because it seems to produce a wave which is "frozen" in space and does not propagate in any direction.

In phenomena like light and sound it is difficult to perceive this circumstance because it is a problem to create two identical beams of light or sound moving in opposite directions. With regard to sound you can read in an encyclopaedia how Kundt managed to do this with a tube filled with sand.

We will study the case of the waves which cross on a guitar string.



3.3 Conclusions about the superposition of waves

When two undulatory movements are propagated through the same region of space, the effect of them both on the medium is called interference.

The interference can give rise to very varied situations, the most important being:

Constructive interference	This is produced between waves of equal frequency and wavelength when **they are in phase**. The result is a wave of equal frequency and wavelength, but with an amplitude equal to the sum of the components.
Destructive interference	This is produced between waves of equal frequency and wavelength if they have a **phase difference of half a wave**. The result is a wave of equal frequency and wavelength, but with an amplitude equal to the difference between the components.
Stationary waves	These are produced between identical waves travelling in

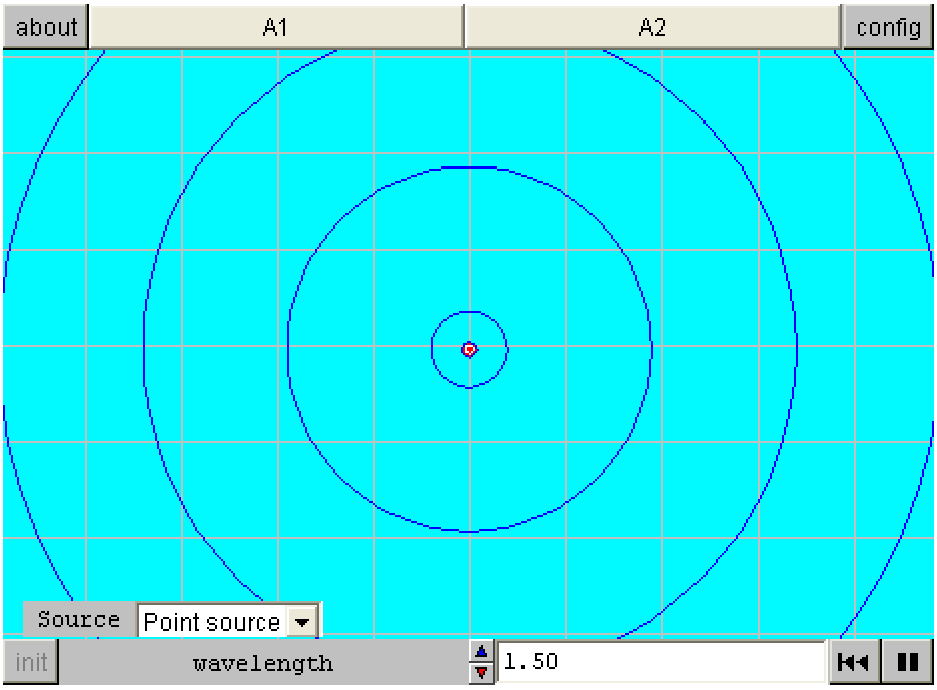
	opposite directions. In the resulting wave there are points (**antinodes**) which vibrate with a maximum amplitude equal to that of the component waves, and points which remain stationary all the time (**nodes).**

4.1 Wavefronts

When we study transverse waves which are transmitted along a rope we are seeing one-dimensional undulatory movements, which only propagate along the rope.

However, light and sound are propagated in all directions from a single source. These are three-dimensional undulatory movements. In this case many points are subjected at the same time to the same vibration and constitute what we call a **wavefront**.

The easiest case to study is that of the waves produced in a pond by throwing a stone or stirring the water with a stick. This is what we investigate in the following visual, where you can choose between a point source and an extended source.



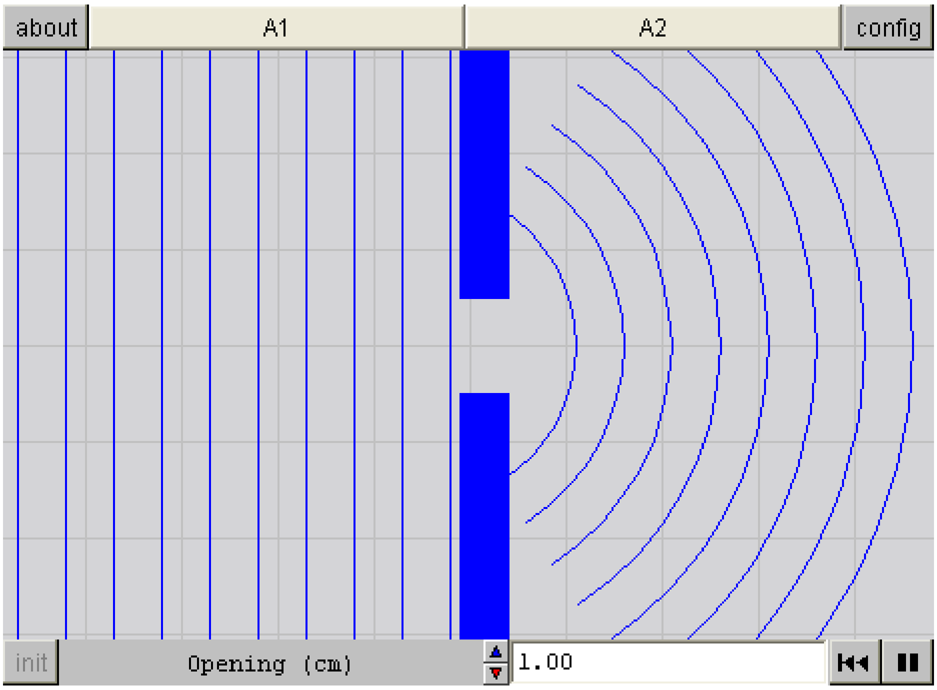
4.2 Diffraction of wavefronts

When an undulatory phenomenon meets a small obstacle in its path it is able to go round it. This is how we are able to hear a conversation taking place on the other side of a wall.

In the same way, when wavefronts meet a small opening, once through, they propagate in all directions.

These two types of behaviour constitute **diffraction**, a characteristic property of undulatory movement to such an extent that the undulatory nature of light was only admitted after it was proved that it experienced diffraction.

In the following visual we will study diffraction in its simplest aspect, when it occurs because an aquatic wavefront finds an opening through which it can propagate.



4.3 Conclusions about wavefronts and diffraction

Undulatory movements which are propagated in more than one dimension constitute **wavefronts, and are formed by points in phase**. The crest of a wave is a good example of a wavefront. A small source emits spherical waves, whereas a plane one emits plane waves. However, at a great distance from the source, the wavefronts may always seem plane.

When the wavefronts meet a small opening or obstacle in their path there is diffraction:

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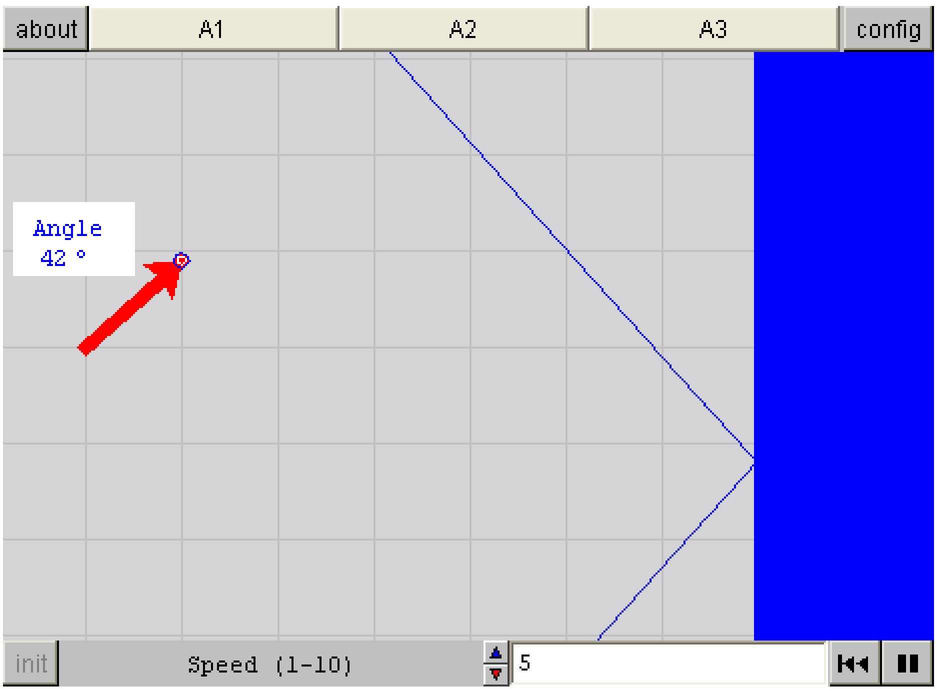
Diffraction is when the wavefronts are propagated in all directions after passing through an opening or round an obstacle. The phenomenon is more perceptible when the size of the opening or obstacle is similar to the wavelength of the wavefront.

5.1 The reflection of waves

When an undulatory movement meets an obstacle in its propagation, the wavefronts change direction, they are reflected.

To study this phenomenon, we will imagine that a wavefront is moving across a pond towards the edge formed by a vertical wall. If this wall does not absorb the energy transmitted by the wave, where will it go after the collision?

In the visual we have provided to study reflection, you can vary the direction of the wavefront by dragging the end of the direction arrow.



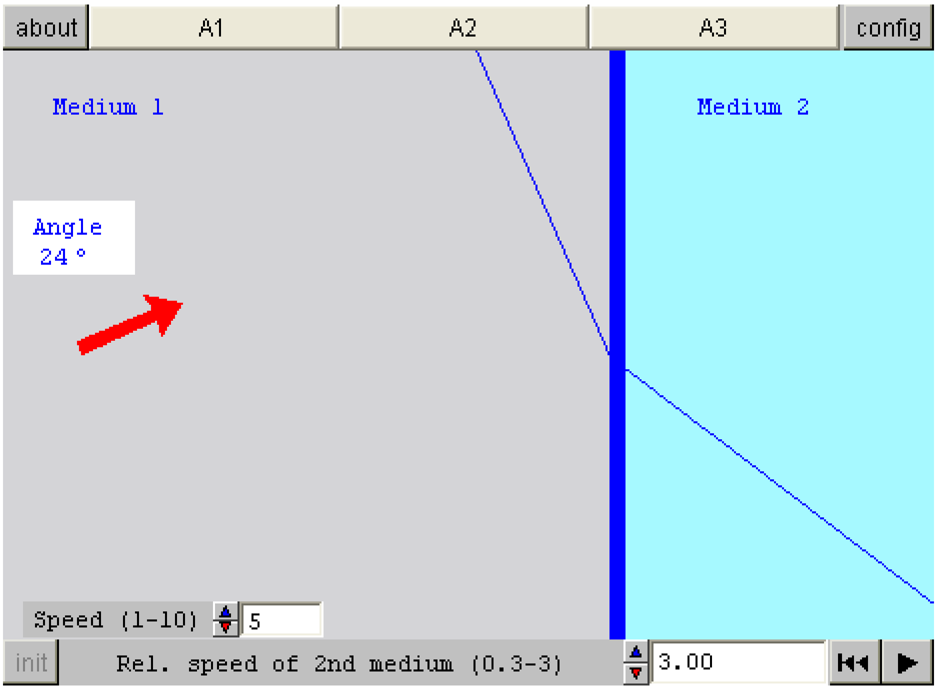
5.2 The refraction of waves

When an undulatory movement passes from one medium of propagation to another, its speed and direction are usually modified. This is the phenomenon called **refraction**. That is why, for example, fish in an aquarium seem bigger when they are inside it than when we take them out.

Although all undulatory movements can be subjected to refraction, we will analyse as an example the case of a wavefront in a pond when the water passes from a shallow part of the pond to a deeper part and vice versa.

In our example you can vary the direction of the front by dragging the end of the direction arrow with your mouse. You can also alter the relation between the velocity in the first medium and the second one. A relative velocity of 1 means that the speed is identical in the two media; if the relative velocity is 2, the speed in the second medium will be double that in the first ...etc.

You can also vary the general speed of the simulation, to adapt it to the characteristics of your computer.

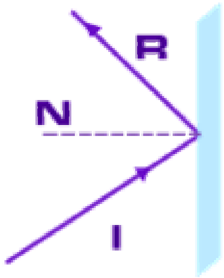


5.3 Conclusions about reflection and refraction

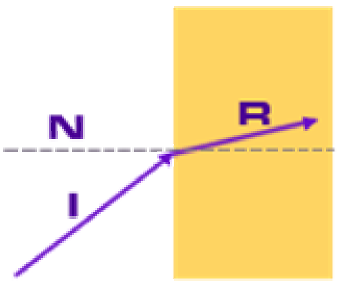
Reflection of waves consists of a change of direction of the wavefront when it meets an obstacle.

Refraction consists of the change of speed of propagation and direction which is produced when an undulatory movement changes medium.

These phenomena respect the following norms:



In **reflection**, the direction of the incident wavefront **I,** forms with the normal **N** at the surface of the obstacle, an **angle equal** to that formed by N with the reflected wavefront **R**



In **refraction**, when changing medium, the direction of the incident wavefront **I** is deviated so that, **if the velocity of the waves in the second medium is lower than in the first** the direction of the refracted wavefront **R approaches the normal N.** If the **velocity of propagation were greater in the second medium R would distance itself from the normal N**.

EVALUATION

1 A wave with a wavelength of 2 m, a period of 1 s. and an amplitude of 0,5 m. interferes with an identical wave with the same phase that propagates in the same direction, therefore...

Visual 3.1

- ☐ the wavelength of the resulting wave is 4 m.
- ☐ the period of the resulting wave is 2 s.
- ☐ the resulting wave has an amplitude of 1 m
- ☐ a destructive interference is produced.
- ☐ a stationary wave is produced

2 What do we call longitudinal waves?

Visual 2.2

- ☐ Waves with a very long wavelength
- ☐ Waves in which the direction of propagation is equal to the direction of the vibration
- ☐ Very long waves
- ☐ Waves with a very short wavelength
- ☐ Waves in which the direction of propagation is perpendicular to the direction of the vibration

3 The phenomenon of diffraction consists in

- [ ] the fact that waves always propagate in a straight line
- [ ] the fact that waves propagate in every direction when they go through an opening
- [ ] the fact that waves change direction when they change media
- [ ] the fact that waves divide into two parts when they encounter an obstacle

4 The maximum speed of a particle in a harmonic vibration

Visual 1.1

- [ ] increases with the frequency and amplitude of the vibration
- [ ] increases with the period and the wavelength of the vibration
- [ ] is always constant during the movement
- [ ] is greater at the ends of the vibration

5 Can an undulatory movement be defined as a way of transporting particles?

Visual 2.1

- [ ] No, the particles may vibrate as the waves go by, but after that they remain where they were
- [ ] Yes, although the particles will move faster than the waves
- [ ] Yes, the particles will move with an undulating trajectory
- [ ] No, particles are never affected by undulatory movements
- [ ] Yes, although the particles may lag behind the waves

6 The phenomenon of the echo is due to

- [ ] the refraction of sound in the atmosphere
- [ ] the reflection of sound on the mountains or other obstacles
- [ ] an illusion of our senses similar to a mirage
- [ ] the diffraction of the sound among the mountain gorges

7 An undulatory movement has a frequency of 10 cycles/s and a wavelength of 3 m. so its speed of propagation is

- [ ] 10 m/s
- [ ] 30 m/s
- [ ] 7 m/s
- [ ] 10/3 m/s
- [ ] 3 m/s

8 Select an example of longitudinal wave and an example of transverse wave

- [ ] Sound is longitudinal and light is transverse
- [ ] The propagation of a vibration on a spring is transverse and sound is longitudinal
- [ ] Light is longitudinal and the propagation of a vibration along a taut rope is transverse
- [ ] Sound is transverse and light is longitudinal

9 When you look at a rock which is under water it seems larger than it is. This is due to

- ☐ the fact that light changes frequency when it comes out of the water
- ☐ the fact that light travels faster in water than in air
- ☐ the fact that light travels slower in water than in the air

10 When someone speaks with a higher pitched voice than another person, this means that

- ☐ they produce sounds of a longer wavelength
- ☐ they produce sounds of a greater period
- ☐ they produce sounds of a greater amplitude
- ☐ they produce sounds of a greater frequency