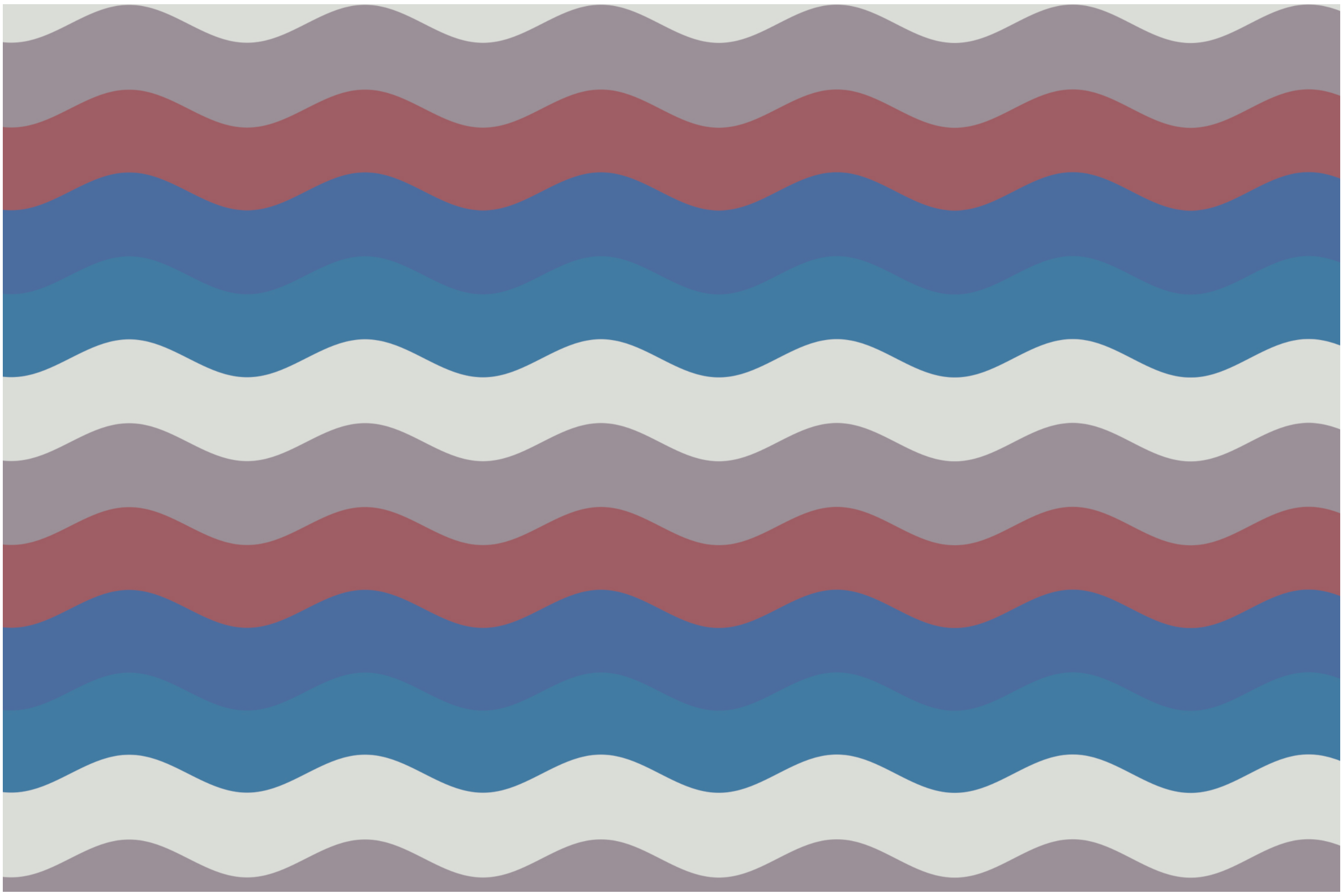
What are waves?



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Introduction

When thinking about waves you may first think of ocean waves. These are a great example of a wave as they are regular, repeating movements of water and a wave may be defined as a periodic, or regularly repeating, disturbance that transports energy from one place to another. In this short course you will discover the difference between transverse and longitudinal waves and gain an understanding of the properties of waves. You will gain an understanding of the process of echolocation and then undertake some online research to discover how bats use echolocation to locate their prey. You will also learn how waves are utilised in healthcare for ultrasound scanning.

This OpenLearn course is an adapted extract from the Open University course S111 *Questions in science*.

Learning Outcomes

After studying this course, you should be able to:

- understand the types of wave
- understand the properties of waves

1 How do you make a wave?

Waves on the surface of the ocean are caused by winds that displace the surface. The same applies in the atmosphere too. The displacement by a force such as the wind pushes the boundary, or interface, between two different density regions away from the state it would have at rest, that is from where the surface would be if it were not moved.

Another way to displace the boundary between fluids of two different densities is to simply throw a stone into a pond (Figure 1).

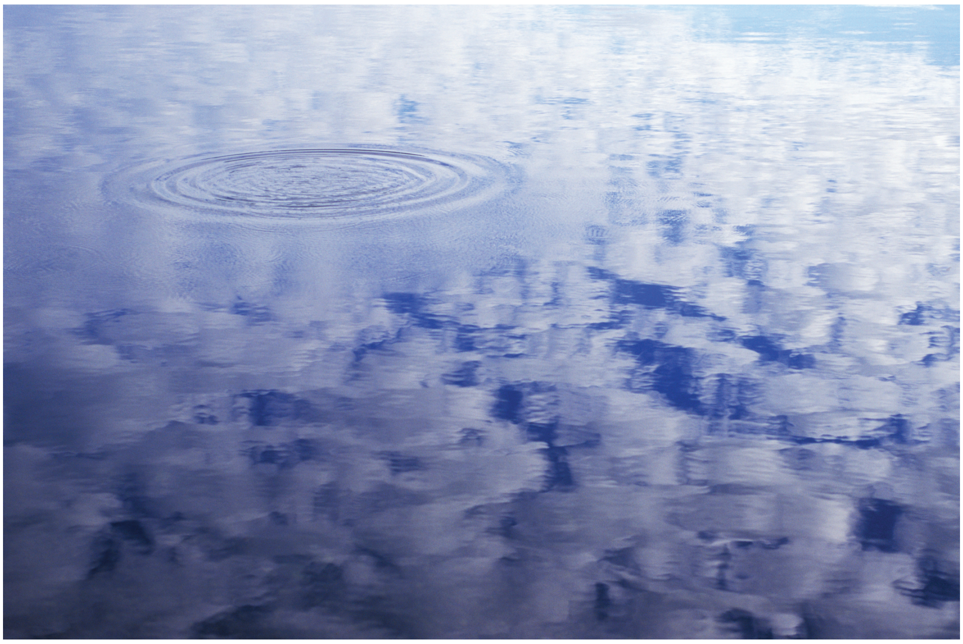

Figure 1 Ripples from a stone thrown in a pond.

We can break down what is happening in Figure 1 into stages:

1. First the stone hits the surface of the water and deflects it downwards.
2. Then the stone breaks through the surface of the water and sinks, effectively leaving a 'hole' in the water.
3. The surface of the water then reforms and rises back up to the level it was before the stone hit. This level is called the mean water level.

- What does the water surface do once it reaches the mean water level?
- It overshoots the mean water level and rises above it.

4. Once the disturbed water surface has reached its maximum height, it starts to descend back towards the mean water level.
5. Again, the disturbed water surface overshoots, this time to below the mean water level of the pond.
6. Once the water surface has reached its maximum depth it starts to rise once more back towards the mean water level.

This cycle or oscillation happens quickly but each time the displacement above and below the mean water level decreases in distance, and eventually the surface comes to rest. This scenario will happen for any fluid disturbed in this way – however, the time it takes for the surface to come back to rest is different depending on its density.

2 Restoring forces

In our stone and water example, the water was initially at rest and at this point the upward and downward forces acting on it were in balance. From Newton’s laws, we know that when the forces are balanced there is no acceleration. However, the impact of the stone disturbs the natural level of the water surface, and because the water is displaced above or below the mean water level the forces are not in balance. It is now worth referring to Newton’s first law of motion which states that:

An object remains at rest or moves in a straight line at constant speed unless it is acted on by an unbalanced force.

Another way of writing this first law would be to say that an object does not accelerate unless it is acted on by an unbalanced force, or equivalently, if an object is acted on by an unbalanced force it will accelerate.

- When the water level is at its lowest point and the forces are most out of balance, in which direction is the force acting to restore the water surface to its mean level?
- The force is directed upwards as the surface of the water returns to the mean water level.

When the water level is at its maximum height there is a force directed downwards.

In both cases this force is called the restoring force.

Every time the surface reaches a maximum displacement a wave crest expands away from the point where the stone entered the water (Figure 1.3). The result is an increasing circle of ripples moving away from the initial disturbance. Eventually, as explained above, the ripples disappear.

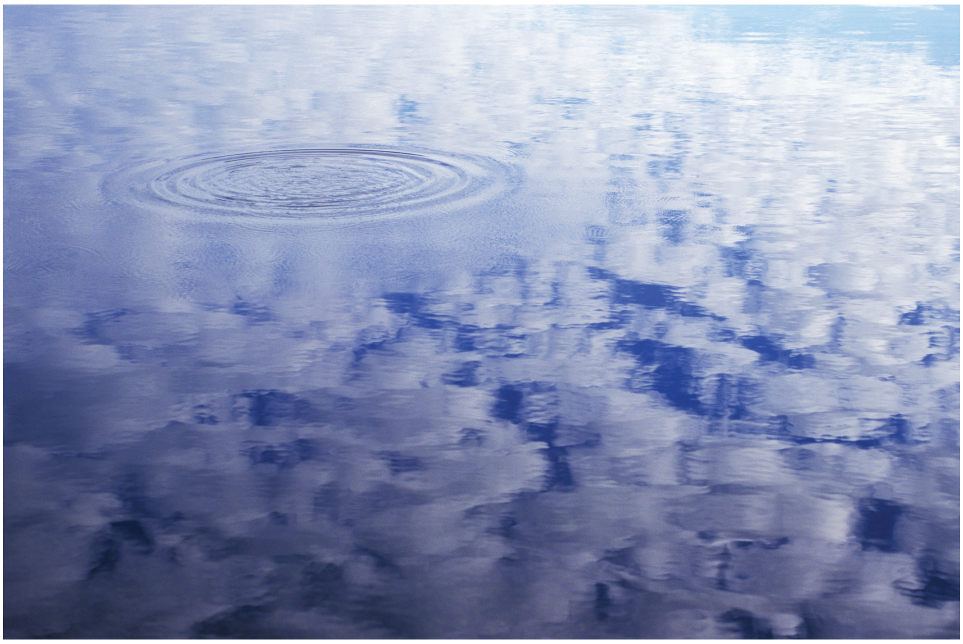

Figure 1 (repeated) Ripples from a stone thrown in a pond.

Because the crests or the ‘maxima’ of the wave get smaller we say this example shows a damped wave.

- What would be the easiest way to make the circle of the expanding wave in Figure 1 larger?
- We could displace the surface by a greater amount by using a larger or heavier stone.

We could frame the whole cycle of what happened in Figure 1 as a system at rest (the flat-water surface) being disturbed (the stone being tossed into the water). Then a wave is generated as the system returns to rest once more.

3 Types of wave

A wave may be defined as a periodic, or regularly repeating, disturbance that transports energy from one place to another.

For example, a stone dropped into the centre of a pond generates a wave on the surface of the water. The wave travels outwards and the energy it transports would eventually cause a cork at the edge of the pond to bob up and down with a regular motion.

Other sorts of wave also exist. It was one of the greatest physicists of the 19th century, James Clerk Maxwell (1831–1879), who established that light is an electromagnetic wave. In fact, light sometimes behaves like a wave and sometimes as a stream of particles.

There are two main wave types, distinguished by the direction of the motion of the particles of which they are made.

3.1 Transverse waves

Figure 1 showed the expanding wave pattern from a stone splash, with the wave moving away from the initial disturbance. The oscillation, that is the up-and-down motion of the water, is at a right angle (90°) to the direction in which the wave propagates, so this is called a transverse wave.

With the stone splash, friction caused the oscillation to be damped and the wave faded. Imagine a system where there is no friction damping the oscillations. If there was a constant source of motion, a cross-section through the surface of the water as the wave moved past would appear as in Figure 2.

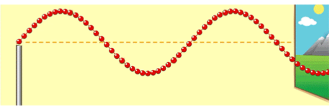

Figure 2 The propagation of a transverse wave being generated on the left. The wave appears to move to the right. (*Wave on a string*, 2017)

In Figure 2 the dots mark fixed points on the surface and the dashed line the location of the undisturbed surface. Focus on locations on the wave where the distance above the undisturbed surface line is the greatest. Each of these places is a peak, and the distance from the undisturbed surface line to the peak is called the amplitude of the wave.

Each of the locations where the distance is the furthest below the undisturbed surface line is called a trough, and the distance from the undisturbed surface to a peak is the same as the distance to a trough. This means the distance from peak to trough is twice the amplitude.

- Do the locations of the peaks and troughs stay at the same point on the horizontal axis?
- No. The locations of the peaks and troughs move to the right.

We say that the wave is propagating to the right. Focusing on the peaks again, the distance from one peak to the next marks one complete cycle, and this distance is known as the wavelength. You can see in Figure 2 that the wavelength is constant. We do not have to choose one peak to the next peak to mark a wavelength – we could use any point on the wave, although of course from one peak to the next is very clear.

Observe what happens if some of the points are highlighted in green (Figure 3).

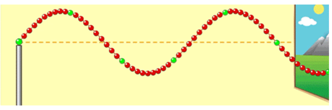

Figure 3 A transverse wave with selected points highlighted in green.

- Do the green dots highlighted in the wave in Figure 3 travel to the right with the wave?
- No. The green dots only oscillate vertically about the undisturbed surface line. In fact, this is the case for all the dots.

While the points on the wave only move in a vertical direction, the wave propagates to the right. Transverse waves have particles moving at right angles to the direction of propagation.

The second type of wave is a longitudinal wave.

3.2 Longitudinal waves

In a longitudinal wave the direction of motion of the particles is in the *same* direction as the wave travels. This can be seen using a long spring called a slinky.

Video content is not available in this format.

Video 1 The propagation of a longitudinal wave along a spring. (0:12 min) (*Longitudinal and transverse waves, 2012*)

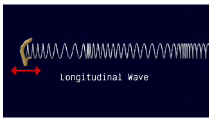

Figure 4 shows how the compressions and rarefactions in a longitudinal wave are similar to the peaks and troughs of transverse waves, but instead of the peaks and troughs being at a distance from an undisturbed level, they are where the particles are pushed together, and apart.

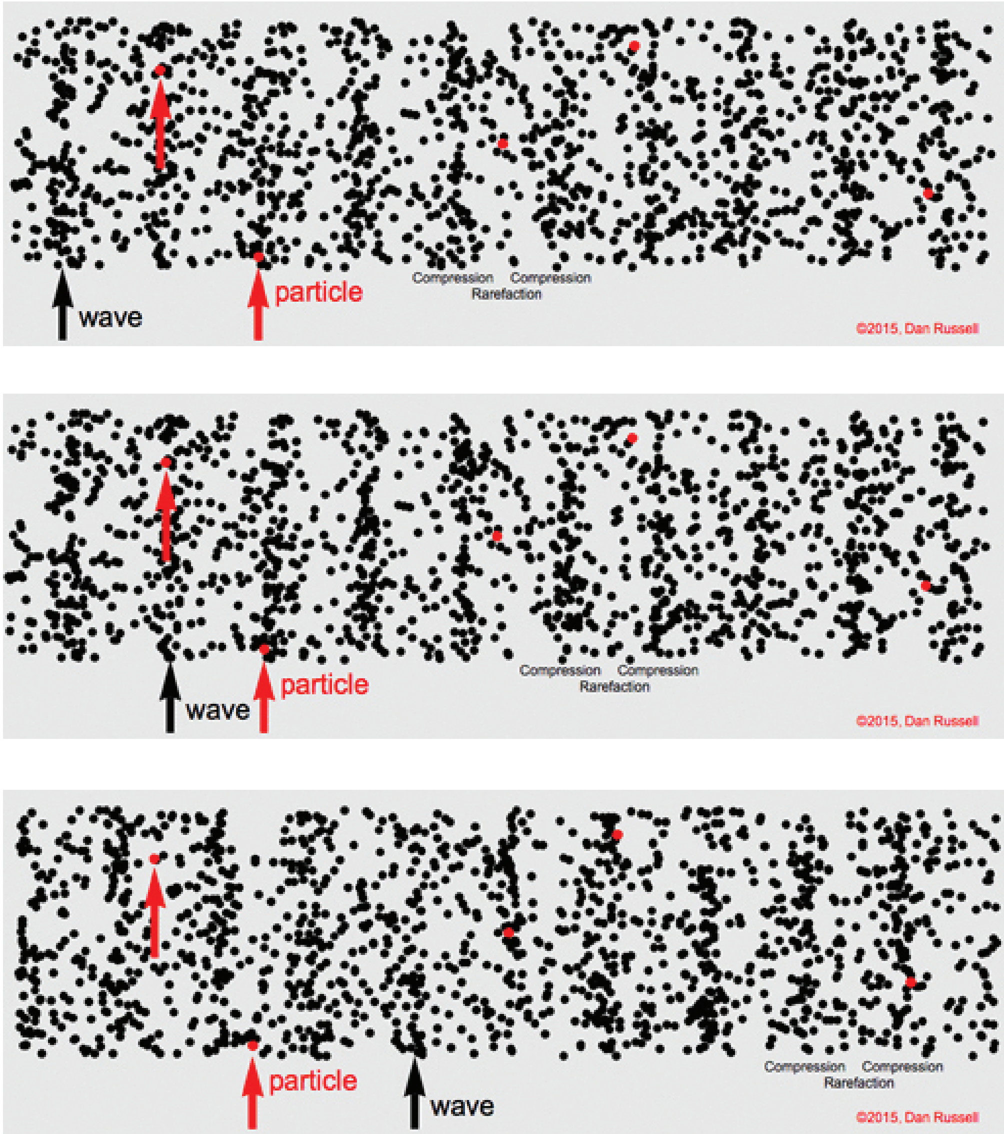

Figure 4 The propagation of a longitudinal wave showing the passage of wave fronts that are comparable to the peaks in Figure 3. The red arrows and dots indicate four particles so that their motion can be more easily observed.

Sound travels as a longitudinal wave. Longitudinal sound waves travel in the atmosphere through the compressions and rarefactions of atmospheric particles.

- Give a reason why sound waves cannot propagate in space.
- Sound waves cannot propagate in space because there are no particles to allow the wave to propagate.

In Figure 2, we visually identified two properties of the wave: its frequency and its amplitude. These can be better illustrated on a graph.

4 Graphical representation of waves

As you learn more about waves and the different situations in which they occur you will see that it is convenient to represent waves graphically. We can plot a wave as a graph in two ways: as a function of *distance* and as a function of *time*. It is important to appreciate the difference between them and the properties of the wave that are represented in both.

Taking the example of a stone splash in a pond, if we take a snapshot of the wave on the surface of a pond at a *fixed point in time*, such as a freeze frame of Figure 2, and plot the vertical position or displacement of a point at the surface as a function of distance from the point where the stone was dropped, we have a wave represented as a function of distance:

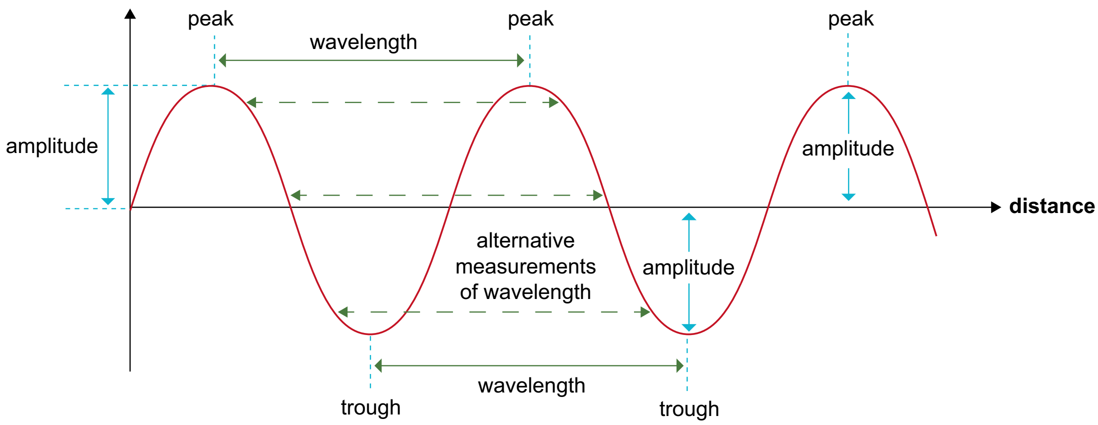

Figure 5 A generic graph showing the properties of a wave that is plotted as a function of distance.

In the case of the stone splash, the vertical axis represents the displacement of the water from the undisturbed water line, but as you encounter waves in other situations, you will come across different units on the vertical axis such as, for example, intensity or voltage. For this reason the vertical axis is unlabelled in Figure 5, as it represents the generic case of any wave that is plotted as a function of distance.

When a wave is plotted with distance on the horizontal axis, the distance from one peak to the next, or one trough to the next, marks one complete cycle, and this distance is known as the wavelength. Note that the peak to peak or trough to trough are merely the easiest places to measure the wavelength or the period. Any full cycle will do, as shown by the dashed lines in Figure 5. In other words, you can measure the wavelength or period as the distance between any pair of equivalent points, that is, points where the wave has the same 'height' and is changing in the same way (i.e. the gradient is either positive for both points or negative for both points).

The maximum vertical displacement of the wave from the undisturbed surface is the amplitude.

We can also plot a wave as a function of time. Using the same example of the stone splash in a pond, if we now focus on a point on the surface *at a fixed distance* from where the stone was dropped, such as one of the green points in Figure 3, and plot the vertical displacement as a function of time, we have a wave represented as a function of time:

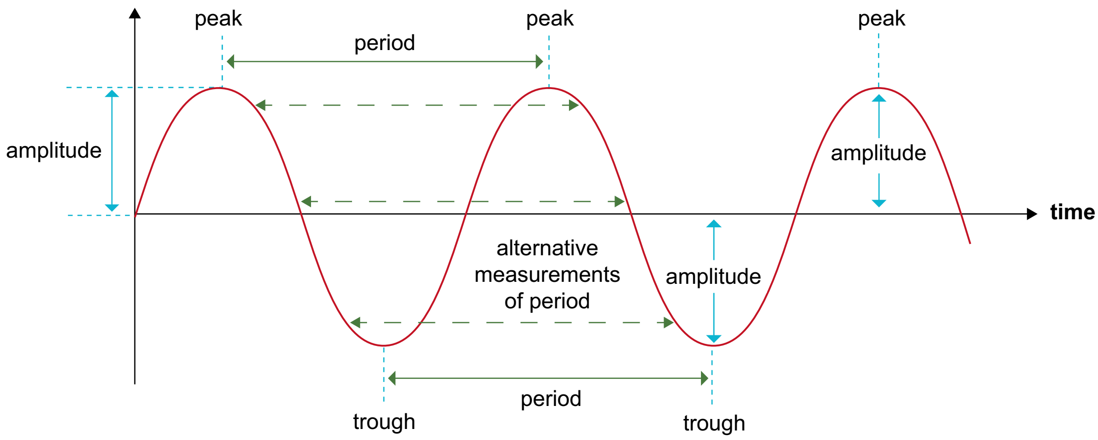

Figure 6 A graph showing the properties of a wave that is plotted as a function of time

When a wave is plotted with time on the horizontal axis, the time taken from one peak to the next, or one trough to the next, marks one complete cycle, and this time is known as the period. As in the previous graph, the maximum vertical displacement of the wave from the undisturbed surface is the amplitude.

So the definitions of wavelength and period are rather similar. The wavelength is a distance and refers to points separated in space but measured at a fixed instant in time; the period is a time interval and refers to instances separated in time but measured at a fixed point in space.

5 Sound and hearing

The substance that a wave travels through is known as the medium, so for a sound wave in air the air is the medium. The frequency of a sound affects how far it can travel through different media. In general, longer wavelength (low frequency) waves travel further than shorter wavelength (high frequency) waves because there is less energy transferred to the medium at these frequencies. For example, a frequency of 10 kHz could travel a few km in seawater but very low frequencies can travel for thousands of km – interestingly, lower frequencies are the ones that the large species whales use to communicate.

The song of a humpback whale (*Megaptera novaeangliae*) consists of waves of many different frequencies – if you listen carefully to Audio 1.1 (*Humpback Whales Songs Sounds Vocalizations*, 2008) you may be able to hear the lowest frequency, which will travel the furthest underwater.

Audio content is not available in this format.
Audio 1 The song of a humpback whale. (1:09 min)

Marine mammals such as the bottlenose dolphin generate higher frequency waves for another purpose – echolocation – as explained in the next section.

5.1 Echolocation

The physics of waves extends into environmental science, with ocean waves, and biology, with the special use some animals make of them. One everyday use of waves relies on the physics of what happens after a wave meets an object and is reflected.

Think back to the times you heard a sound echo.

If you made the sound, then you would know that the longer the gap between the sound and the echo, then the further away the object that the sound was reflecting from. If you know the speed the sound wave is travelling at and the exact time it takes for the echo to be heard, then you can work out exactly how far away the object reflecting the sound is.

This is the principle of radar which is used to map and track the locations of aircraft in the sky and ships on the sea, in this case using electromagnetic waves. It is also the same principle used by ships that send a sonar (SOund Navigation And Ranging) pulse of sound into the ocean and ‘listen’ to the reflection to find out how deep the water is.

It is also the principle used by some animals to navigate and find their food.

Bottlenose dolphins can hear in the range 75 Hz to 150 kHz; they can also generate sounds in this frequency range and, by sensing the returning echo, they can become aware of both the shape of their environment – and their food (Figure 7).

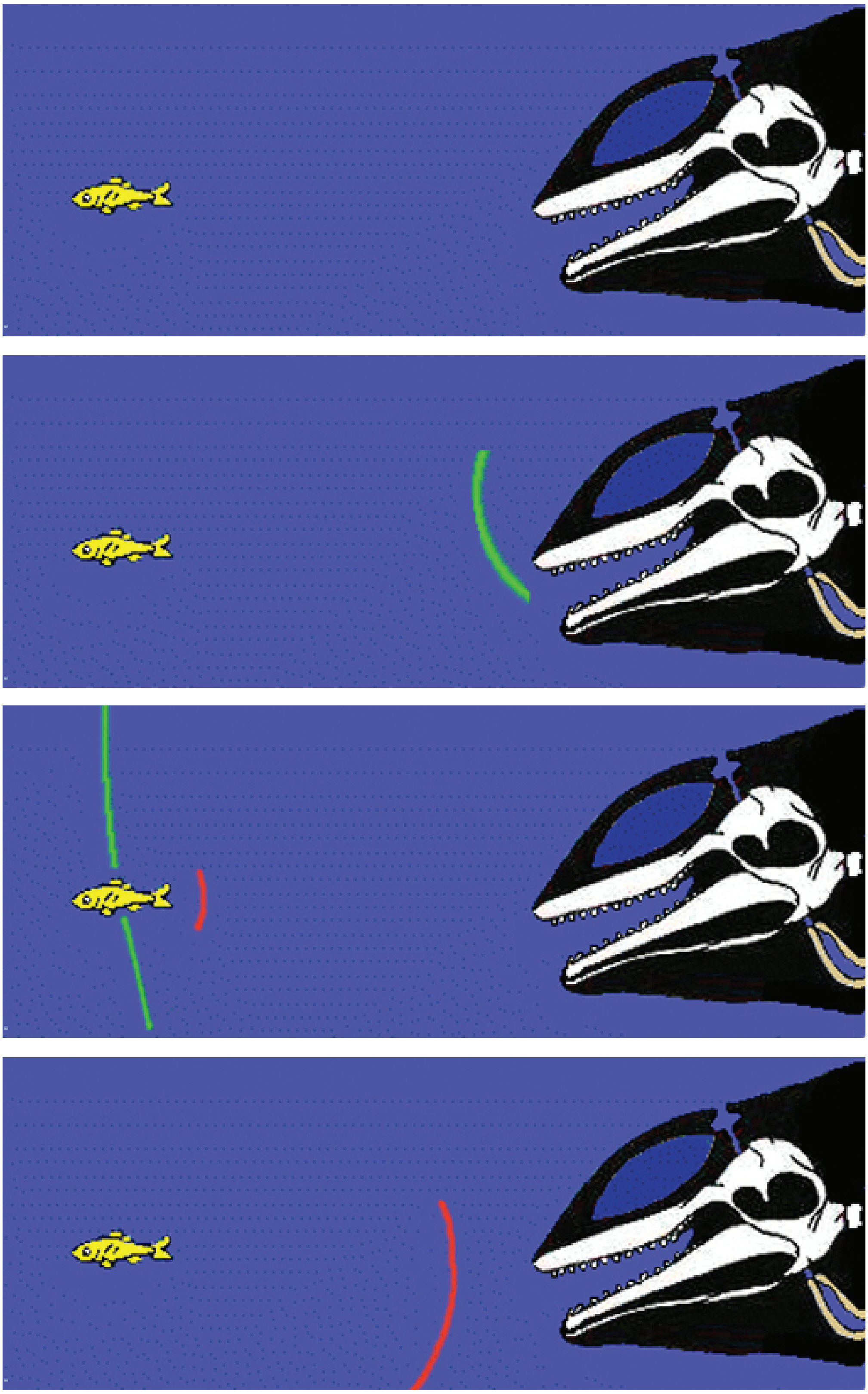

Figure 7 A dolphin projects a series of clicks at different frequencies towards its prey. By sensing the returning echoes, it can determine the distance to its prey and environment.

Other animals that commonly use ultrasound are the bats. These species show amazing diversity and mostly feed on insects – although some feed on fish, fruit, nectar and, in the case of the vampire bat, on mammalian blood. In flight, bats generate very short bursts of ultrasonic sound with their larynx that is emitted via the nose and mouth. Most bats have a nose shaped to focus the sound and some can even vary the width of the beam they project. From the returning echoes they can detect their prey and their environment.

It is amazing that both marine mammals and land animals have independently evolved a sonar navigation and feeding tool. Different species of bats have gone even further.

Activity 1 Bats jamming bats

Allow approximately 30 minutes for this activity.

In this activity you will read a primary scientific research paper and a blog post. You will then answer some questions. Reading the primary paper and blog post will give you an insight into how scientists communicate their research to others.

The primary research paper was published in 2014 in the international journal *Science*. *Science* is published weekly by the American Association for the Advancement of Science (AAAS) and is a peer reviewed academic journal. Scientists communicate their research in articles in peer-reviewed academic journals. Peer review means that, before the article can be published, other academics in the same field review it for quality and accuracy. Not all articles submitted to peer-reviewed journals get published and it is not unusual for the reviewers to ask questions and suggest edits to the original paper before publication. Peer review acts as a form of self-regulation and provides credibility to the research published.

Blogs are regularly updated websites or webpages which are often run by individuals or small groups. They are not peer reviewed and are often written in a less academic and more conversational style.

The primary research paper is fairly technical but you will not have to remember the technical detail. Do look at the figures and note how the data are presented in graphical format. Select the link below to read the full Corcoran A.J. and Conner W.E. (2014) article and then select the link to the blog post by Ed Yong. You will then need to answer the questions that follow.

- Corcoran A.J. and Conner W.E. (2014) Bats jamming bats: Food competition through sonar interference, *Science,* vol. 346, no. 6210, pp. 745–747.
- Ed Yong a blog post in National Geographic's Phenomena.

After doing this, answer the following questions based on your review.

1. What was the key finding of Corcoran and Conner in their paper published in *Science*?

Answer

Mexican free-tailed bats (*Tadarida brasiliensis*) use a particular type of vocal 'social calls' or squeaks (sonar) to detect their prey. The sonar are echolocation signals. Corcoran and Conner discovered that these bats can block or 'jam' the sonar of other bats deliberately to stop their bat competitors from finding prey.

2. What additional information did Ed Yong's blog post give about tiger moths and bats?

Answer

Tiger moths can release ‘ultrasonic clicks’ which interfere with bats sonar and so divert the bats from a precise strike on the moths. The clicks protect the tiger moths from the attacking bats.

3. What differences did you notice between the Corcoran and Conner paper and Ed Yong’s blog post?

Answer

There are quite a few differences between the two, some are listed below, but you may have noted other differences as well.

- The Corcoran and Conner paper uses more technical language, such as the Latin name for Mexican free-tailed bats (*Tadarida brasiliensis*), the blog post does not use technical language.
- The Corcoran and Conner paper is significantly longer than the blog post.
- The Corcoran and Conner paper has 3 technical figures which include graphs, the blog post has two photographs, one of a Mexican free tailed bat and the other of the Corcoran and Conner experimental set up.
- The Corcoran and Conner paper has an ‘abstract’ at the start and 22 references which are cited in the paper are listed at the end of the paper.

5.2 Ultrasound imaging

A similar use of principles of echolocation has been developed for medical imaging purposes. For example, a pregnant woman can visit a medical practitioner and have an ultrasound scan of their fetus. This scan uses the physics of waves to make a completely safe and non-invasive image of the inside of a human. The practitioner places a piece of equipment called a transducer on the surface of the woman’s skin. The transducer emits very high frequency waves of usually 3–7 MHz (i.e. 3–7 million hertz) into the body. These frequencies are harmless, and the transducer listens for the echoes. Through computer analysis the returning echoes can be turned into an image that depicts what is beneath the skin (Figure 8).

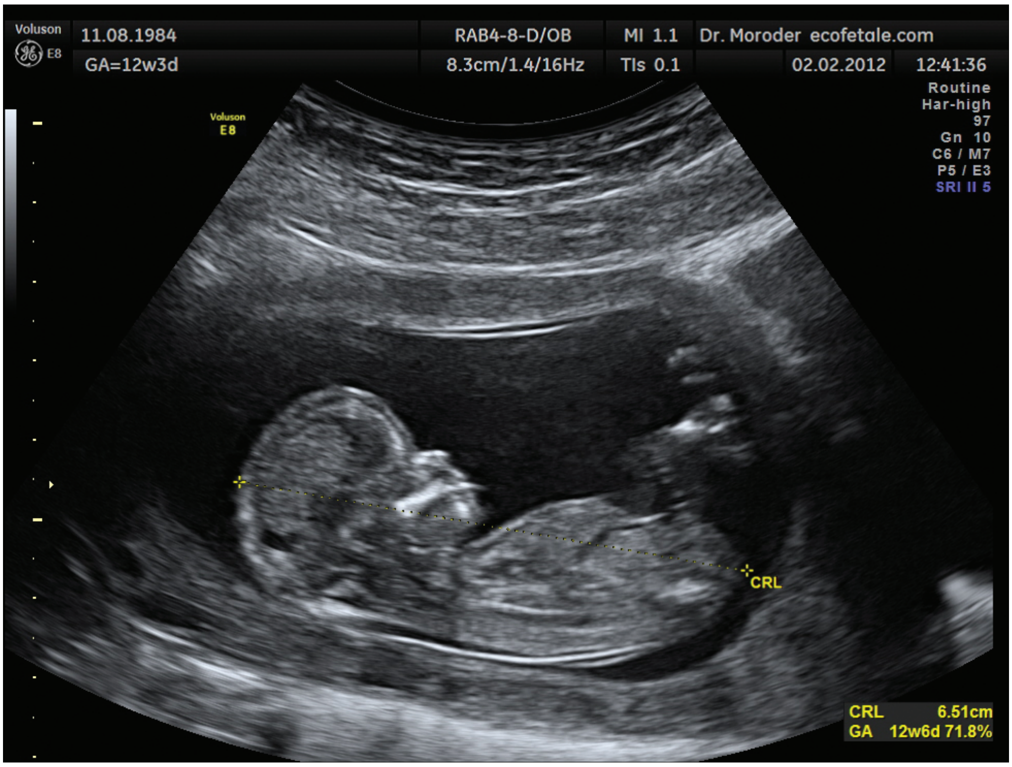

Figure 8 The results of a non-invasive ultrasound scan showing a 12-week old fetus in a woman's womb.

Conclusion

We have looked at transverse and longitudinal waves in water and the air and some of their properties. All waves are linked to a behaviour that is both oscillatory and periodic because they repeat after some amount of time. But it's not only waves that display this type of behaviour.

The key concepts and principles you have studied in this part are:

- types of wave
  - Waves can be seen as oscillations along fluid boundaries where restoring forces return the boundary to rest.
  - In transverse waves the particles move at right angles to the direction of wave propagation.
  - In longitudinal waves the direction of motion of the particles is in the same direction as the wave propagation.
  - Waves can be described in terms of their amplitude, wavelength, and/or period.
- properties of waves
  - Animals can use waves for communication, navigation and finding prey.
  - Humans can use ultrasound waves for medical imaging.

This course is part of a suite of introductory science courses on OpenLearn.

The content of these courses comes from the Open University course S111 *Questions in science*. Take a look at the other OpenLearn courses that are part of this set here.

References

Corcoran A.J. and Conner W.E. (2014) 'Bats jamming bats: Food competition through sonar interference' *Science,* vol. 346, no. 6210, pp. 745–747.

Humpback Whales Songs Sounds Vocalizations (2008) Uploaded by Sookietex for the National Park Service, U.S. Department of the Interior. [Online]. Available at https://archive.org/details/HumpbackWhalesSongsSoundsVocalizations (Accessed 19 June 2019).

Interference and feet (n.d.) Dr Mirjam S. Glessner, Adventures in Oceanography and Teaching. [Online]. Available at http://mirjamglessmer.com/experiments/experiment-interference-of-waves/ (Accessed 19 June 2019).

Longitudinal and transverse waves (2012) Uploaded to YouTube by Animations for Physics and Astronomy, the Physics and Astronomy Animation Project at Penn State University. Available at https://www.youtube.com/watch?v=7cDAYFTXq3E (Accessed 19 June 2019).

Wave interference and beat frequency (2016) Open-source, interactive, educational demonstrations provided by Academo. [Online]. Available at: https://academo.org/demos/wave-interference-beat-frequency/ (Accessed 19 June 2019).

Wave on a string (2017) PhET Interactive Simulations provided by University of Colorado, Boulder. [Online]. Available at: https://phet.colorado.edu/en/simulation/wave-on-a-string (Accessed 19 June 2019).

Acknowledgements

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