

Surfing hills of water – the science of waves

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Abstract The formation of waves as used for surfing close to the shore is described and explained, and linked to other wave topics that are covered in school science. Of course, there are differences because the wave activity is influenced by many factors, such as the weather and the shape of the shoreline, which make the wave patterns much more complicated. However, gaining experience in understanding the behaviour is a great help in developing skill in this sport.

I was talking with a group of 12-year-old students in a school about their experiences of surfing and how waves are created when one of them said that waves are like ‘hills of water’. Their school is close to a long ocean beach in New Zealand and many of the students enjoy water sports in their free time, including surfing (ridden by standing) and boogie boarding (usually ridden in prone position on a shorter, light board). After asking them for some explanation about waves and where they come from, I heard one student use the word wavelength. When the conversation ended, I enquired:

‘Did I hear you use the word wavelength?’

‘Yes.’

‘What’s that?’

‘It’s how far apart the waves are from each other.’

In the same moment, the student used her hands to demonstrate a distance apart. That conversation sparked my interest in what the 12-year-old said and what I hope to describe in this article. The science of waves is usually overlooked in surf magazines but the following description highlights wave formation and their changing nature as they travel to our coastlines.



Figure 1 Slow peeling waves originate from deep water in the ocean; as they approach land waves slow down, get closer together and become higher; the waves in this photograph are 3–4 m high and are travelling at about 4 m s^{-1} as they approach the beach

Wind can do two things

Waves are made from swell, which is generated by wind, and wind can do two things – either produce swell from a long way off, called ‘ground swell’, which originates in the deep ocean, often thousands of kilometres or more from the shoreline, or ‘wind swell’, which is due to local conditions. You can often identify a ground swell by the longer distance between waves (longer wavelength). What is usually noticed with ground swells is that they produce sets of 3 to 10 waves with long periods of time between the sets and less chop (Figure 2). Wind swell on the other hand usually produces a choppy water surface, with waves close together because they have travelled such a short distance.



Figure 2 Ground swell waves have often travelled thousands of kilometres from deep in the ocean to the coast; these are the most desired waves for a surfer as they are less choppy and have a consistent period of time between them

Wave formation

Wind or air movement occurs because of the difference between high and low pressures over the ocean, and it’s the wind that transfers its energy to the water. Imagine a completely flat, glassy ocean surface with a gradually increasing wind blowing over the surface. Tiny bumps called ‘capillary waves’ are formed through the disturbance of the wind, not only pushing over the water surface but also pushing down. A little like if you were

to blow down on water in a dish with your breath in a series of blows – this causes the water surface to go down and then spring back up. The growth rate of waves produced in this way is linear; these early waves progressively becoming bigger and bigger with time. At this stage the sea surface looks ruffled and choppy. Once these capillary waves start to be formed (Figure 3), the wind also causes ‘turbulent eddies’ at the rear of the wave, which increase its height. As the wave grows in height, the force of gravity acting down also increases so there is a limit to the wave height. Waves can’t just grow and grow indefinitely – there is a balance reached between the generating wind force and the weight of the water.

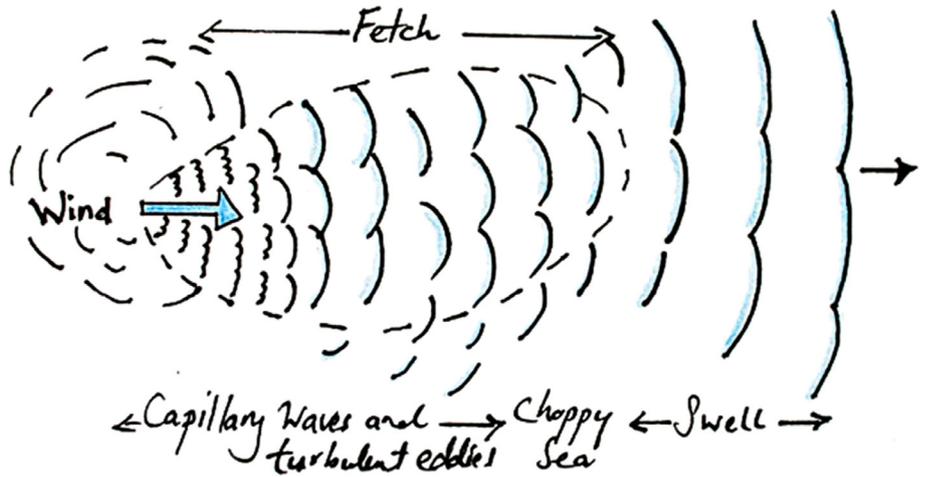


Figure 3 Wind creates waves, starting from tiny capillary waves, which are reinforced by turbulent eddies; this zone is described as the fetch, where the wind blows continuously

Free travelling waves

The area over which the wind is blowing is described as the ‘fetch’ (Figure 3) and it is this patch of water surface that causes the generation of the waves by the storm. Here the waves are constantly supplied with energy by the moving air. However, once the wind dies down, the waves continue to travel away from the fetch and the ocean surface has a wide range of different height waves. The free travelling waves are no longer under the influence of the wind and very little energy is lost when swell travels in the deep ocean. One important aspect to consider is that, in deep water, the travelling waves do not move the body of water from one place to another. Waves are not ocean or tidal currents, they are purely carrying the energy of the initial storm. This can be easily demonstrated by flicking a rope at one end, so that a pulse is made from one end to the other. The pulse that is generated does not move the actual rope along, it simply transfers the up and down motion of the rope from one end to the other. The ocean surface behaves just like a rope, but it is attached to the water beneath it!

Some of the main features (Figure 4) of a free travelling wave are:

- the amplitude, A , which is the maximum distance from the equilibrium position that a particle of the water moves due to the pulse or wave;
- the wavelength, λ , (the Greek letter lambda), which is the

distance between two points that are in phase with each other;

- the period, T , which is the time interval in seconds between repeated waves and is determined by the source; and
- the wave velocity, v .

Since the wave travels a distance of one wavelength in the time for a complete pulse, which is T , its velocity is given by the equation $v = \lambda / T$.

An example would be if a surfer notices that while floating in the same place, it takes one minute for 3 wave peaks to pass her by and she estimates that there are 10 metres between the crests. The period of time for one wave to pass her is $60 \div 3 = 20$ s. The velocity of the wave is $v = 10 \text{ m} \div 20 \text{ s} = 0.5 \text{ m s}^{-1}$.

Wave refraction

In deep water, wave height of 5 to 6 metres is small in comparison to the depth of the ocean, which could be 5 to 6 kilometres. Wave speed is governed by the wavelength, that is how far apart one wave is from the next (Figure 4). The longer the wavelength, the faster the wave, because of a more effective air–water interface from the weight of the water and from surface tension. As the swell begins to move away from the storm centre, different wavelengths and wave heights occur. Waves

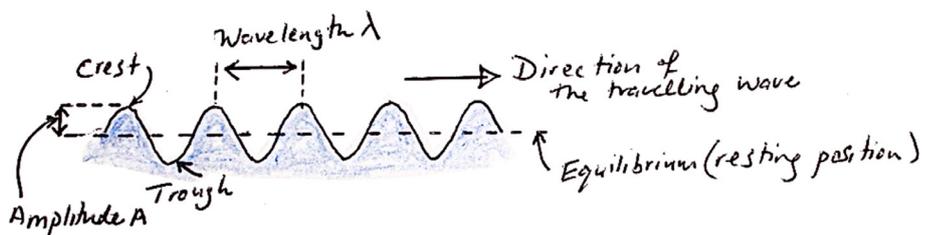


Figure 4 Parts of a travelling wave

with shorter wavelengths get lost into deep water and waves with longer wavelengths continue their march to the coast. They are faster and race out in front of the shorter ones, and the swell stretches out across the ocean.

However, once the waves experience more shallow water as they come closer to the coast, (Figure 1), they slow down (velocity v decreases) and they bunch up (wavelength λ decreases). This change of direction of a wave as it travels into a different region is called refraction. As the water waves pass between a deep region and a shallow region they obey Snell's law of refraction – when one part of a wave travels more slowly than another, the wave 'bends' towards the slower part (Figure 5). One interesting feature of refraction is the period T of the waves – the time between one wave and the next remains the same, no matter whether they move from deep to shallow water or vice versa.

Aerial photographs of waves show that their wavelength remains constant as they travel through deep water. Because $v = \lambda/T$, where T is determined by the source and λ is found to be constant, it follows that the speed of waves must be constant in deep water.

At the shore it is a different matter. The waves get closer together and they get higher (the amplitude increases). Both these effects must be caused by a decrease in speed because the period cannot alter.

Wave refraction is also influenced by the period of the waves (and the wavelength) because longer waves generate larger water motions, which 'reach down' further beneath the surface and start to change direction before shorter ones. The longer the period, the greater the refraction, and in a typical new swell approaching the coast the amount of refraction is far greater than it is later in the life of the swell.

Breaking waves

The shape of the sea floor plays a big part in determining surfing conditions. The ideal ocean floor shape is triangular, gradually tapering from shallow to deeper water. Such a set-up would generate perfect lefts and rights down either side with the swell coming in at right angles to its apex. A perfect set-up is a consistently peeling wave on all types of swell. Unfortunately, these are rare, and because wind and waves erode the beach in this manner, they seldom last for more than a few weeks. However, there are some examples of point breaks (Figures 7 and 8) around the world that are formed from rocks, so could last for many years. The action of the ocean floor has more effect on the bottom of the wave than the top, and thus slows down the bottom more than the top. This effect is progressively more noticeable as the water gets shallower, so a tipping point is reached when the top of the wave overtakes the bottom, making

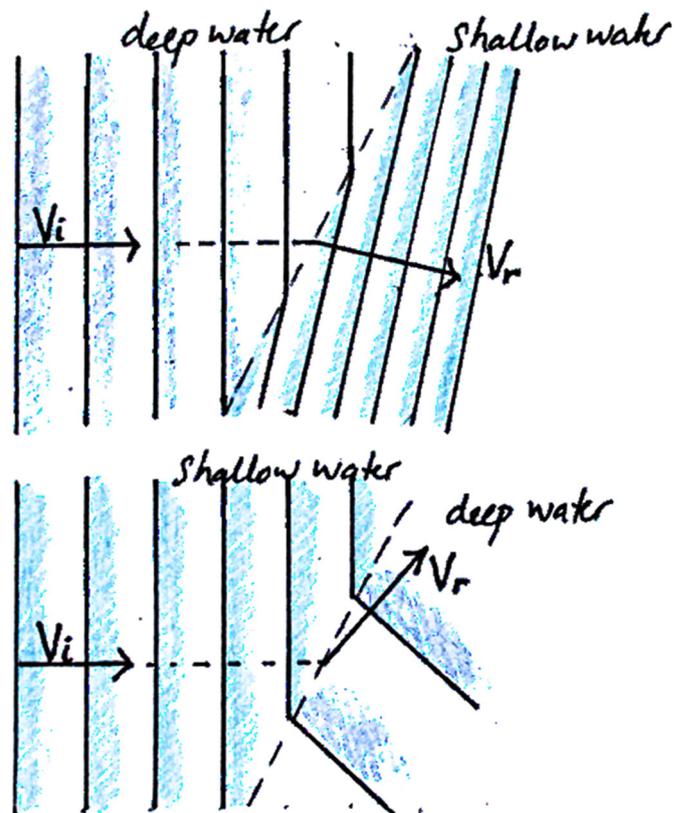


Figure 5 Diffraction of water waves. Waves (lines representing crests) moving at different speeds. Waves that go from deep to shallow water slow down ($v_r < v_i$) and bunch up (wavelength λ_r decreases). Waves that move from shallow water to deep water get faster ($v_r > v_i$) and spread out (wavelength λ_r increases). The period T stays the same no matter the depth of water, but the result is that the wave changes direction.

it spill forward, so the wave breaks. One major factor that influences the shape of the wave when it breaks is how the water depth changes. If the wave suddenly passes over extremely shallow water such as a reef break, the top will be going much faster than the bottom so the wave will throw out as it breaks. Figure 6 demonstrates how the wave breaks closer to the shallow water, where the rocks are located.



Figure 6 A tipping point is reached when the top of the wave (the crest) overtakes the bottom (the trough), making it spill forward, so the wave breaks

Surf breaks

Surf breaks come in three main types and depend on different physical environments of the ocean floor: the *reef break* (submerged rock or coral); the *point break* (round stones or a sandy bottom close to a headland or an island); and the *beach break* (usually sandbars along a coast).

Reef waves are characteristically hard-breaking – they have strength when they break, standing up abruptly where the reef surface begins. They are not for beginners, as a fall onto a shallow rock can result in serious injury. However, they break consistently in the same place and this makes the wave predictable and powerful. They often occur where a river runs out from the land, causing a break in the reef and creating a deep channel where the water runs out.

The point break depicted in Figure 7 is where the swell refracts around a point of land jutting out to sea and breaks in one direction – in this example it is breaking on the right. It is usually a long-breaking wave, breaking close to rocks or the headland where the wave slows down. The wave in the deeper water continues at a faster speed so the wave front bends. The refraction of water waves is the bending of waves as they travel from deep water around the point into shallow water.

In Figure 8, the wave closer to the rocks slows down because the depth is shallow, but the part of the wave in deeper water is faster and pulls out in front so the wave ‘bends’ to fit the bay.

The beach break (Figure 9) is where refraction occurs through shifting sandbars, which cause the wave to bend and break over the shallow water depth. Looking from above at a sandy coastline, you would usually see a series of beach breaks and repeating rips (deep water with no waves) taking the water back out. If the beach is small, waves can break across the entire bay by dumping or ‘closing out’ on the sand and an undercurrent can form in the middle or at the sides of the bay to return the water to the sea.

Sea breezes can affect the wave surface

If you live somewhere by the coast and the air temperature warms quickly, for example to 25–30°C in the summer time, it’s likely a sea breeze will freshen in the afternoon. In places where the climate is generally colder, or where it is cloudy throughout the day, a sea breeze seldom occurs. Coastal deserts or urban regions with little vegetation are places where sea breezes are most likely to occur because of rapid heating of the land. Generally, in the morning the land begins to warm by the Sun, and by midday the warm air caused by the heat

rises because it is less dense than cold air, through the process of convection. Cooler air from the sea sweeps in, replacing the rising warmer air. It is this movement



Figure 7 A right-hand point break where the wave breaks on the right-hand side closer to the land

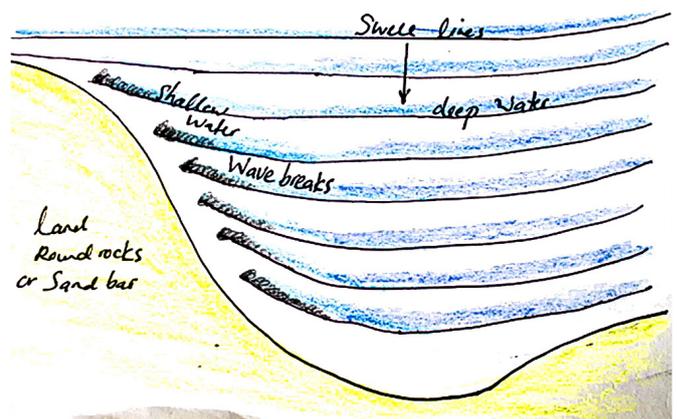


Figure 8 A top view illustration depicting a left-hand point break where the waves (crests drawn as lines) typically bend around a rocky headline or sandy bar to the left; the waves in the shallow water closer to the headline bunch up, slow down and gain in height, and they break as they get close to the ocean floor



Figure 9 A typical beach break with a mix of sandbars and rips running along the coast

of air rushing in to replace the warm air rising above the land that causes the onshore or sea breeze. The opposite occurs as the land cools down in the evening – the wind can swing around to the opposite direction causing a land or offshore breeze. The offshore breeze can help to smooth out a choppy wave surface and pull up the height of the breaking wave. The best effect of a light offshore wind is to ‘clean up’ the waves, which helps the face of the wave stand up. The offshore breeze helps to shrink the shorter waves, leaving the more anticipated long waves for the surfer. Shorter waves are slower and less powerful, which makes them easier to flatten down by the offshore wind. Interestingly, as the sea temperature warms through the summer months, the temperature difference between the land and the sea gradually decreases. For example, if the air temperature of the land

is, say, 26°C at midday and the water temperature has risen through the summer to the early 20s, then it is less likely that a sea breeze would occur because the temperatures of the sea and the land are too similar.

Conclusion

I hope that this article helps to build further understanding of the complex world of water waves. I have made the effort to keep the mathematics simple but place greater emphasis on descriptive explanations of the science of waves. The idea for this article came from the students who inspired the conversation about ‘hills of water’. Thank you.

All photographs and diagrams are by the author and his colleague Sam Jenkins.

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Save the dates...

ASE Annual Conference, Sheffield Hallam University - Thurs 6 Jan to Sat 8 Jan

Europe's biggest science education gathering - the Association for Science Education Annual Conference - is moving back to reality this January, with a full face-to-face programme kicking off on Thursday 6 January.

The ASE conference is an essential event for science educators concerned with both their own continuing professional development and their organisation's ongoing strategy for delivering the best quality science education.

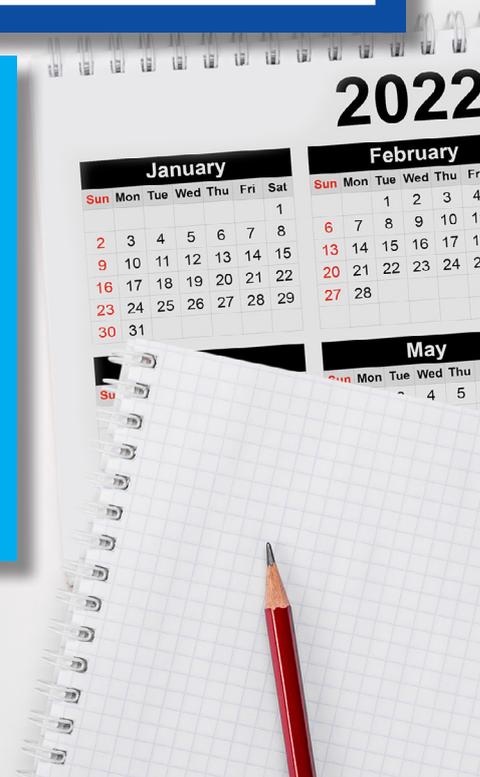
We're in the process of pulling together the programme, but some of the themes already confirmed include: Diversity, Sustainability, Scientific Literacy Post-Pandemic and Curriculum Features Development.

We'll be sharing full details in future issues of SSR, but in the meantime make sure you save those dates!



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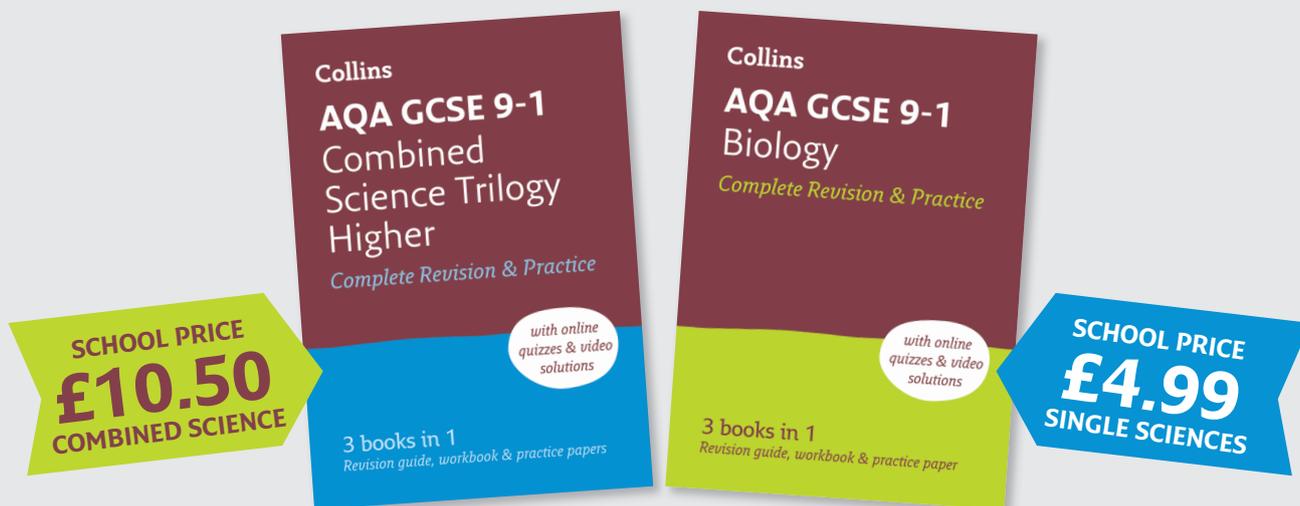


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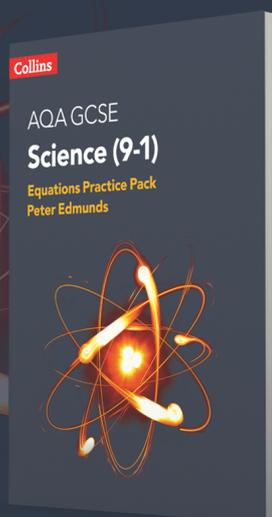
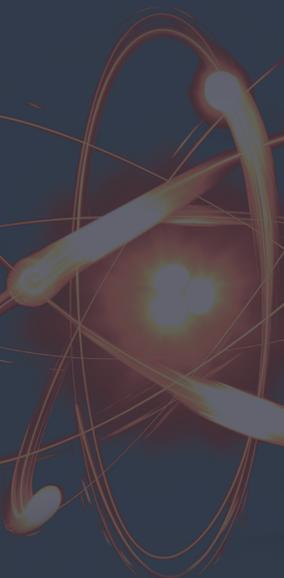
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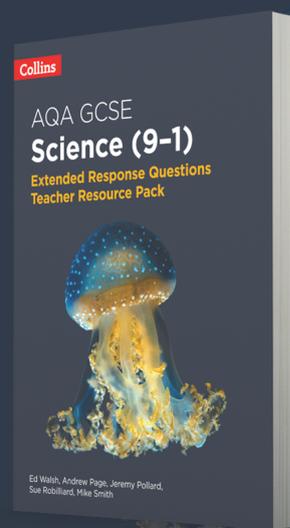
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