WAVE MOTION

Let's start with an intuition-building exercise that deals with waves in matter, since they're easier than light waves to get your hands on. Put your fingertip in the middle of a cup of water and then remove it suddenly. You'll have noticed two results that are surprising to most people. First, the flat surface of the water does not simply sink uniformly to fill in the volume vacated by your finger. Instead, ripples spread out, and the process of flattening out occurs over a long period of time, during which the water at the center vibrates above and below the normal water level. This type of wave motion is the topic of the present section. Second, you've found that the ripples bounce off of the walls of the cup, in much the same way that a ball would bounce off of a wall. In the next section we discuss what happens to waves that have a boundary around them. Until then, we confine ourselves to wave phenomena that can be analyzed as if the medium (e.g., the water) was infinite and the same everywhere.

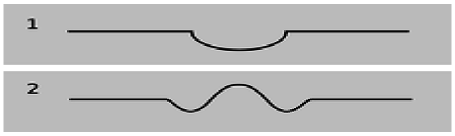


Figure a: Your finger makes a depression in the surface of the water, 1. The wave patterns starts evolving, 2, after you remove your finger.

It isn't hard to understand why removing your fingertip creates ripples rather than simply allowing the water to sink back down uniformly. The initial crater, a/1, left behind by your finger has sloping sides, and the water next to the crater flows downhill to fill in the hole. The water far away, on the other hand, initially has no way of knowing what has happened, because there is no slope for it to flow down. As the hole fills up, the rising water at the center gains upward momentum, and overshoots, creating a little hill where there had been a hole originally. The area just outside of this region has been robbed of some of its water in order to build the hill, so a depressed “moat” is formed, a/2. This effect cascades outward, producing ripples.

There are three main ways in which wave motion differs from the motion of objects made of matter.

Figure b: The two circular patterns of ripples pass through each other. Unlike material objects, wave patterns can overlap in space, and when this happens they combine by addition.

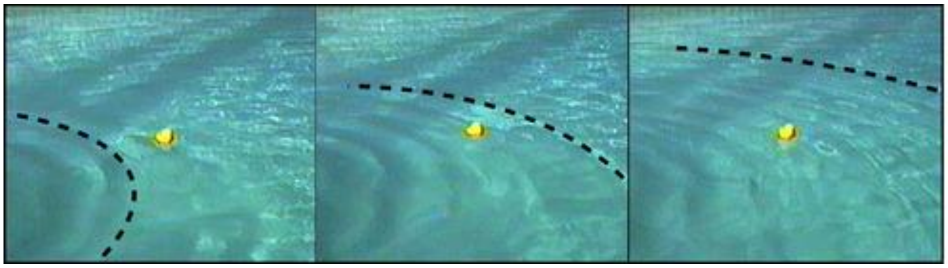
Superposition

If you watched the water in the cup carefully, you noticed the ghostlike behavior of the reflected ripples coming back toward the center of the cup and the outgoing ripples that hadn't yet been reflected: they passed right through each other. This is the first, and the most profound, difference between wave motion and the motion of objects: waves do not display any repulsion of each other analogous to the normal forces between objects that come in contact. Two wave patterns can therefore overlap in the same region of space, as shown in figure b. Where the two waves coincide, they add together. For instance, suppose that at a certain location in at a certain moment in time, each wave would have had a crest 3 cm above the normal water level. The waves combine at this point to make a 6-cm crest. We use negative numbers to represent depressions in the water. If both waves would have had a troughs measuring −3 cm, then they combine to make an extra-deep −6 cm trough. A +3 cm crest and a −3 cm trough result in a height of zero, i.e., the waves momentarily cancel each other out at that point. This additive rule is referred to as the principle of superposition, “superposition” being merely a fancy word for “adding.”

Superposition can occur not just with sinusoidal waves like the ones in the figure above but with waves of any shape.

The figures on the following page show superposition of wave pulses. A pulse is simply a wave of very short duration. These pulses consist only of a single hump or trough. If you hit a clothesline sharply, you will observe pulses heading off in both directions. This is analogous to the way ripples spread out in all directions when you make a disturbance at one point on water. The same occurs when the hammer on a piano comes up and hits a string.

Experiments to date have not shown any deviation from the principle of superposition in the case of light waves. For other types of waves, it is typically a very good approximation for low-energy waves.



c / As the wave pattern passes the rubber duck, the duck stays put. The water isn't moving with the wave.

The medium is not transported with the wave.

The sequence of three photos in figure c shows a series of water waves before it has reached a rubber duck (left), having just passed the duck (middle) and having progressed about a meter beyond the duck (right).

The duck bobs around its initial position, but is not carried along with the wave. This shows that the water itself does not flow outward with the wave.

If it did, we could empty one end of a swimming pool simply by kicking up waves! We must distinguish between the motion of the medium (water in this case) and the motion of the wave pattern through the medium. The medium vibrates; the wave progresses through space.

self-check:

In figure d, you can detect the side-to-side motion of the spring because the spring appears blurry. At a certain instant, represented by a single photo, how would you describe the motion of the different parts of the spring? Other than the flat parts, do any parts of the spring have zero velocity? (answer in the back of the PDF version of the book).

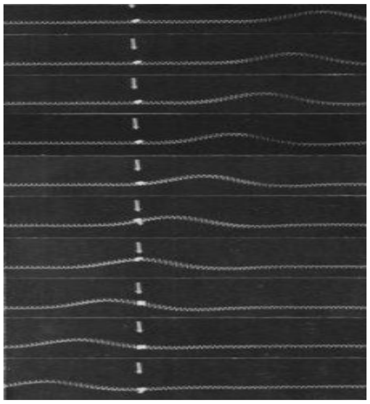
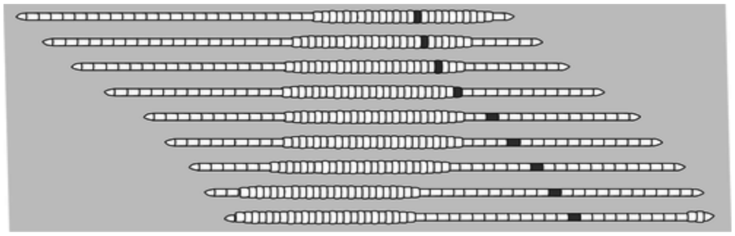


Figure d: As the wave pulse goes by, the ribbon tied to the spring is not carried along. The motion of the wave pattern is to the right, but the medium (spring) is moving from side to side, not to the right. (PSSC Physics)

EX 1: A WORM

The worm in the figure is moving to the right. The wave pattern, a pulse consisting of a compressed area of its body, moves to the left. In other words, the motion of the wave pattern is in the opposite direction compared to the motion of the medium.



EX 2: SURFING

The incorrect belief that the medium moves with the wave is often reinforced by garbled secondhand knowledge of surfing. Anyone who has actually surfed knows that the front of the board pushes the water to the sides, creating a wake --- the surfer can even drag his hand through the water, as in in figure e. If the water was moving along with the wave and the surfer, this wouldn't happen. The surfer is carried forward because forward is downhill, not because of any forward flow of the water.

If the water was flowing forward, then a person floating in the water up to her neck would be carried along just as quickly as someone on a surfboard. In fact, it is even possible to surf down the back side of a wave, although the ride wouldn't last very long because the surfer and the wave would quickly part company.

e / Example 2. The surfer is dragging his hand in the water.

A wave's velocity depends on the medium

A material object can move with any velocity, and can be sped up or slowed down by a force that increases or decreases its kinetic energy. Not so with waves. The speed of a wave, depends on the properties of the medium (and perhaps also on the shape of the wave, for certain types of waves). Sound waves travel at about 340 m/s in air, 1000 m/s in helium. If you kick up water waves in a pool, you will find that kicking harder makes waves that are taller (and therefore carry more energy), not faster. The sound waves from an exploding stick of dynamite carry a lot of energy, but are no faster than any other waves. In the following section we will give an example of the physical relationship between the wave speed and the properties of the medium.

EX 3: BREAKING WAVES

The velocity of water waves increases with depth. The crest of a wave travels faster than the trough, and this can cause the wave to break.

Figure f: A breaking wave.

Once a wave is created, the only reason its speed will change is if it enters a different medium or if the properties of the medium change. It is not so surprising that a change in medium can slow down a wave, but the reverse can also happen. A sound wave traveling through a helium balloon will slow down when it emerges into the air, but if it enters another balloon it will speed back up again! Similarly, water waves travel more quickly over deeper water, so a wave will slow down as it passes over an underwater ridge, but speed up again as it emerges into deeper water.

EX 4: HULL SPEED

The speeds of most boats, and of some surface-swimming animals, are limited by the fact that they make a wave due to their motion through the water. The boat in figure g is going at the same speed as its own waves, and can't go any faster.

No matter how hard the boat pushes against the water, it can't make the wave move ahead faster and get out of the way. The wave's speed depends only on the medium. Adding energy to the wave doesn't speed it up, it just increases its amplitude.

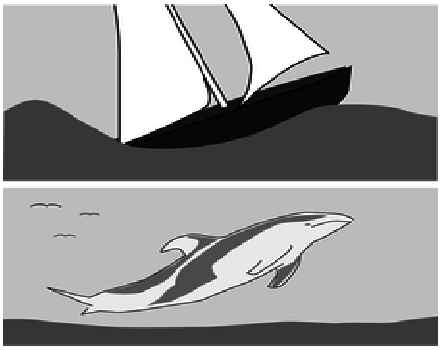


Figure g: The boat has run up against a limit on its speed because it can't climb over its own wave. Dolphins get around the problem by leaping out of the water.

A water wave, unlike many other types of wave, has a speed that depends on its shape: a broader wave moves faster. The shape of the wave made by a boat tends to mold itself to the shape of the boat's hull, so a boat with a longer hull makes a broader wave that moves faster. The maximum speed of a boat whose speed is limited by this effect is therefore closely related to the length of its hull, and the maximum speed is called the hull speed.

Sailboats designed for racing are not just long and skinny to make them more streamlined --- they are also long so that their hull speeds will be high.

Wave patterns

If the magnitude of a wave's velocity vector is preordained, what about its direction? Waves spread out in all directions from every point on the disturbance that created them. If the disturbance is small, we may consider it as a single point, and in the case of water waves the resulting wave pattern is the familiar circular ripple, h/1. If, on the other hand, we lay a pole on the surface of the water and wiggle it up and down, we create a linear wave pattern, h/2. For a three-dimensional wave such as a sound wave, the analogous patterns would be spherical waves and plane waves, i.

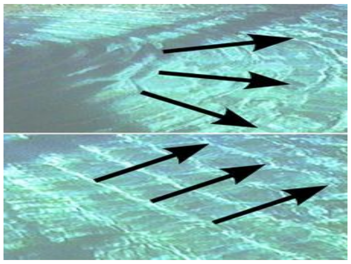
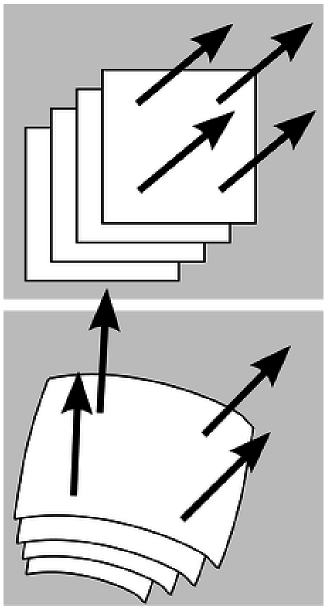


Figure h: Circular and linear wave patterns.



i / Plane and spherical wave patterns.

Infinitely many patterns are possible, but linear or plane waves are often the simplest to analyze, because the velocity vector is in the same direction no matter what part of the wave we look at. Since all the velocity vectors are parallel to one another, the problem is effectively one-dimensional. Throughout this chapter and the next, we will restrict ourselves mainly to wave motion in one dimension, while not hesitating to broaden our horizons when it can be done without too much complication.

Source: http://physwiki.ucdavis.edu/Fundamentals/06._Waves/6.1_Free_Waves