Oceans in Motion: Waves and Tides

Waves

Waves are among the most familiar features in the ocean. All waves work similarly, so although we are talking about ocean waves here, the same information would apply to any other waves you might discuss in science classes.

Ocean waves transport energy over vast distances, although the water itself does not move, except up and down. This may surprise you, but if you think about it, once you are past the breakers on your raft, you pretty much just bob up and down. (You might drift up the beach….we'll get to that.) This **orbital motion** is explained in the figure below:

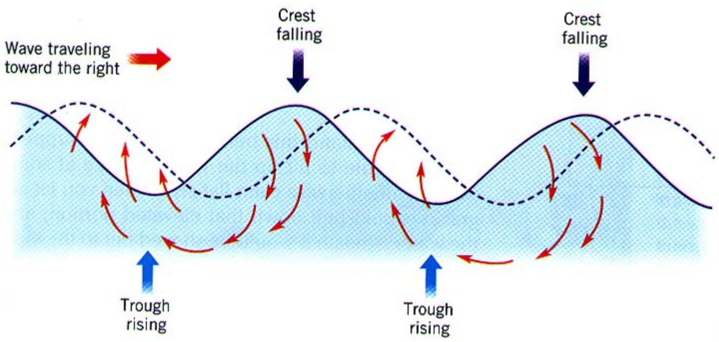


Figure 9.10
Waves travel because gravity pulls the water in the crests downward. Forced out from beneath the falling crests, the falling water pushes the former troughs upward, and the wave moves to a new position, as indicated. (Notice that the actual motion of the water itself beneath these waves is circular or *orbital*, which confirms our experience that we are carried up and forward as the wave approaches, and down and back as it passes.)

There are waves of all sizes and shapes rolling into the beach at any given time. If they're not stopped by anything, waves can travel across entire ocean basins and so the waves at your beach might be from a storm half a world away. The most familiar ocean waves are caused by the wind. These are **wind-driven waves**. This sort of motion is set up anytime two fluids rub together, and remember that the atmosphere is essentially fluid. Waves caused by underwater disturbances such as earthquakes, landslides, or volcanic eruptions are called **tsunamis**. These waves are typically tens to hundreds of kilometers long. The gravitational pull of the sun and moon on the earth causes the tides which are actually **tidal waves**. We'll get back to that.

So we can talk about waves, it's important that you know some of their parts. The following list refers to the figure below:

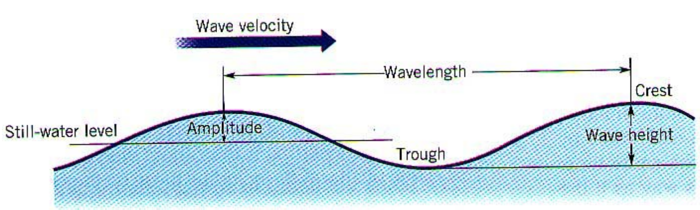


Figure 9.2
Illustration of some wave terminology.

crest-the very top of the wave

trough-the hollow between two crests

wave height-the vertical distance between the top of one wave crest and the bottom of the next trough

wavelength-the horizontal distance between any one point on one wave and the corresponding point on the next

wave steepness-the ratio of height to length

amplitude-the maximum vertical displacement of the sea surface from still water level

(half the wave height)

period-the time it takes for one complete wavelength to pass a stationary point

wave speed-the velocity with which waves travel

deep water waves-waves that are in water that is deeper than half their wavelength

shallow water waves-waves that are in water that is shallower than 1/20 their wavelength (the important difference on these last two is whether or not the sea floor influences the motion of the wave)

One waves motion is completely independent of any other wave motion. When two groups of waves meet, they pass right through each other. This is obvious if you consider light and sound waves. When two people talk or your child has both the TV and the stereo on, you can hear both. One set of sound waves doesn't garble the other. Likewise you can see two objects at the same time. What does happen, though is that waves can either add up or cancel each other out as they pass through one another. This property is called **superposition**. If a crest from one wave happens to line up with the trough of another, they cancel each other out. This is called **destructive interference**. If two waves line up crest to crest or trough to trough, they add up. This is called **constructive interference**. This is why waves at the beach are all different sizes. There are lots of different wave groups coming in, and they're interfering with each other in different ways.

Standing waves result when two equal waves are going in opposite direction and in this case you get the usual up/down motion of the water surface but the waves don't progress. These are common in coastal areas where waves reflect off seawalls, ship's hulls, or breakwaters. They're also common in swimming pools. A special type of standing wave is a **seiche**. You can observe this by sloshing around in your bathtub (or, if you're less adventurous try walking with coffee). When you get just the right steady wave frequency going in your tub or your cup, the motion quickly builds up and water or coffee sloshes all over the place. When harbors are designed, care has to be taken to give water built up in seiches some way out other than sloshing up into the first floor condos.

Waves Hitting Things

When a wave hits a hard vertical surface it is **reflected**. In other words, the wall pushes the water back just as hard as it got pushed, and sets up waves in the other direction. With constructive interference, you end up with bigger and therefore stronger waves. This is why, in the long run, solid seawalls are not good for saving property from the ocean. You end up creating stronger waves that cause even more erosion.

Waves are also **refracted**. When you're at the beach, it appears as if the waves are mostly coming ashore in a straight line. If those waves were generated all over the place out at sea, how is it they're all heading the same direction? Here is an example of shallow water waves (waves getting steered by the seafloor). They may come in at an angle, but the side that hits shallow water first gets slowed down by friction and the other side "catches up" bending around until they're parallel with shore. This is shown in the figure.

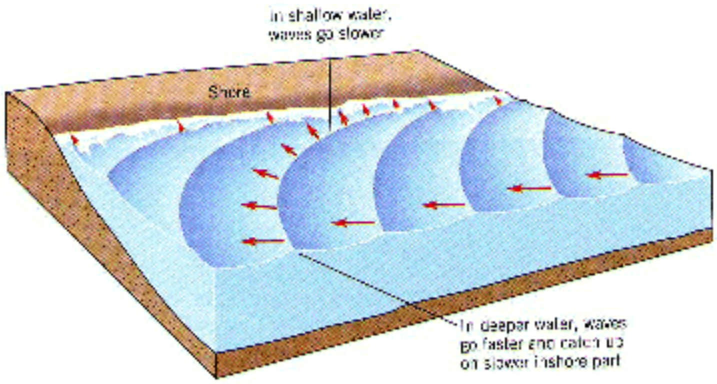


Figure 9.17
Refraction of waves coming in toward shore.

You have no doubt noticed when you swim in the ocean that you tend to drift down the beach. This is called **longshore drift** and is a consequence of these refracting waves. Along with you, a lot of sand is getting moved along, and this is one way that our barrier island migrate up and down the coastline.

Interestingly, because tsunamis have such long wavelengths, they are shallow water waves and so the seafloor steers them around. This is one reason it is so difficult to predict where these waves will have an impact, even if you know what started them and where. The other amazing thing is that they typically travel about 750 kilometers per hour (or 500 miles per hour)! Because they're so long and low, it's hard to identify one until it's close to shore and by then it's too late to warn coastal residents.

Surfing

Why is surfing good in some places and lousy elsewhere? To understand this, you need to understand how and why waves break. You've got lots of waves all nicely refracted and heading into the beach. The ones in front start really getting dragged by the bottom and so they slow down. This allows the ones behind them to ride up their backs. As the distance between the rows of waves decreases, all that wave energy gets condensed into a narrower and narrower space and has to go somewhere, so the wave gets taller. Remember that the waves energy goes around in an orbit under the wave. These taller waves require stronger and bigger orbits, which you notice in the fact that just behind where the waves break, you really get pushed alternately toward shore and away from shore (note that unless it's a **rip current**, these waves are not actually going to push you out to sea---there's just that circular motion going on). Meanwhile, the waves are slowing down still more and at some point, the orbit speed gets ahead of the wave speed, and the wave sort of runs over itself. You see this as the wave cresting, and since the water can't support it, it breaks, releasing all the energy, and propelling your surfboard forward.

There are 3 basic types of breaking waves, depending on the type of shoreline they're hitting. **Spilling breakers** occur on gently sloping coasts where the waves break slowly and over a long distance, with the crest spilling gently down the front of the wave. That’s what we have here. If the coast is steeper, the waves slow down more quickly and so the crest curls way over the front of the wave and plunges down towards the base---in other words it curls. This is a **plunging breaker** and is a good surfing wave like you’d have in Hawaii. In some cases, where the coastline if very steep, the wave builds up very suddenly and breaks right onto the beach. These are **surging breakers**.

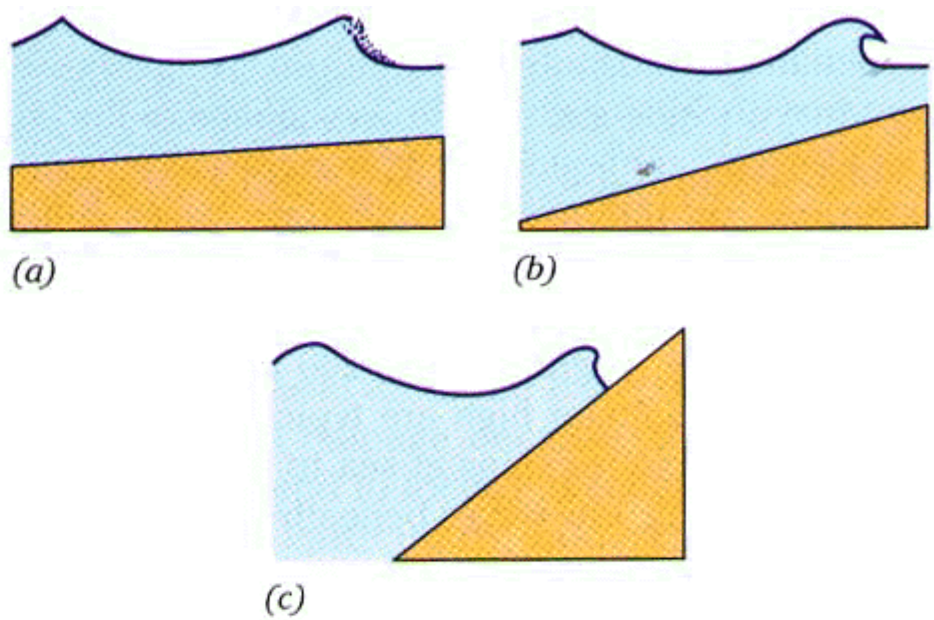


Figure 9.22

Illustration of the three different types of breakers. (a) Spilling breakers are generally found where there is a gently sloping bottom. (b) Plunging breakers are found where the bottom slope is moderate. (c) Surging breakers are found where the bottom slope is so steep that the wave doesn’t break until it is right at the shoreline.

Tides

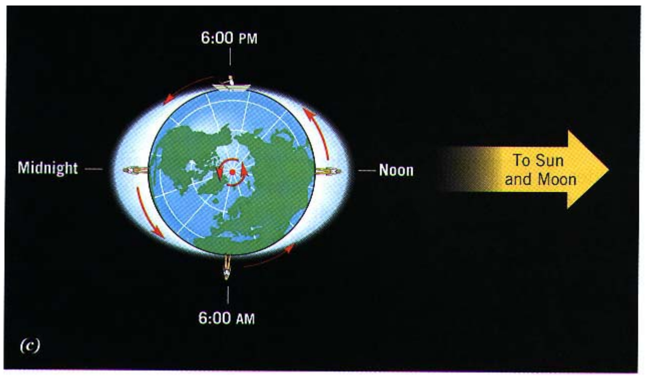
The biggest waves in our oceans are the tides. These are caused by the gravitational forces between the earth and the sun and the moon. The moon has the biggest influence because it is close. It essentially pulls up a bulge in the ocean on the side of the earth closest to it. It actually pulls up the land too, but not as much. There is also a bulge on the side opposite the moon. This one is tougher to understand. I’ve heard it explained two ways that seem to help:

1. Because of centrifugal force (more an effect of the earth and moon revolving together than an actual force), the ocean on the side of the earth opposite the moon is sort of thrown outward, like you are when you go around a bend in your car.

2. Imagine a race car, minivan, and bicycle starting a race. All three accelerate, and from the point of view of the minivan, the race car shoots out in front and the bicycle gets left behind. The way they

spread out depends on the *differences* in rate of acceleration. Similarly, the side of the earth nearest the moon gets pulled out harder than the side away from the moon relative to the earth itself. The nearside shoots out ahead, and the backside gets left behind.

I don't care which of these you prefer, as long as you get that there is this bulge on BOTH sides of the earth even though the moon is only on one side! So this bulge sort of sits there and we rotate around such that sometimes we're under the bulge and sometimes we're not. Since it takes 24 hours for the earth to complete a rotation, plus we have to catch up a little because while the earth was rotating, the moon was revolving around the earth, we are directly under a bulge, or experiencing high tide, about every 6 1/2 hours.



View of the Earth from above the North Pole. The tidal bulges are aligned with the Sun and Moon. As the Earth spins, we are carried through these bulges, thus experiencing two high tides and two low tides per day. In the case illustrated here, we would experience the high tides at noon and midnight, and the low tides at 6:00 PM and 6:00 AM, as indicated.

Twice daily tides like this are called **semidiurnal tides**. It is also possible to have only one high and one low tide per day. That would be a **diurnal tide**. Partly this depends on your latitude, but it turns out that some 400 variables go into predicting the tide at any one place, so it isn't nearly this simple.

The sun tugs on the oceans too, but since it's so far away, it has less influence than the moon. You can see the influence when the moon and sun and earth are all lined up. This would be during a full moon and a new moon. With both the sun and moon pulling the same direction, we get extra high high tides and extra low low tides (a big **tidal range**). These happen twice a month and are called **spring tides.** In between these, during the quarter phases of the moon, we get tides with the lowest ranges. These are called **neap tides**.

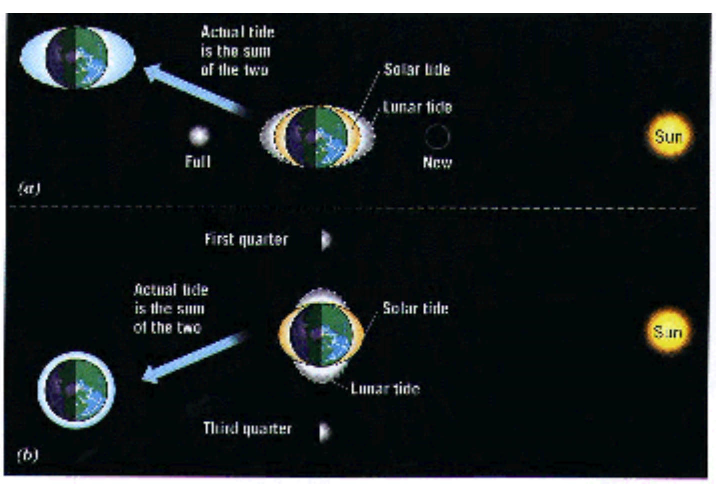


Figure 9.36

(a) When the Moon is new or full, the solar and lunar tides are in the same directions, giving the extra large spring tides. (b) When the moon is at first or third quarter, the solar and lunar tides are 90° to each other, tending to offset each other, and giving the smaller neap tides. Due to superposition, the actual tides we see are the sum of these two components. (For example, in the second case, we will see the water surface averaged out. The two components roughly cancel each other out: one's high on the other's low, and vice versa.)