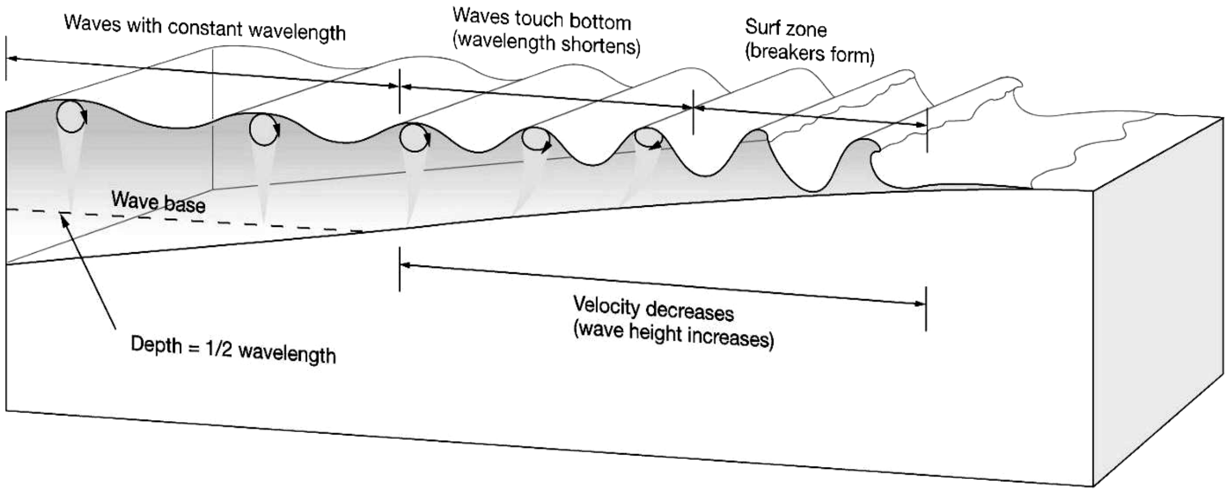
Name ____

Wave Behavior Lab



From Trujillo and Thurman, Essentials of Oceanography.

Deep Water Waves

A wave moving across the ocean surface can be described by several variables. One is the **wavelength (L)**: the horizontal distance from one wave crest to the next wave crest. Another is the **wave period (T)**: the time between two successive wave crests passing the same point. Since velocity equals distance traveled divided by time, **wave velocity (V),** the speed of the wave across the ocean surface, equals the wavelength divided by the wave period (**V = L/T**).

When a wave moves across the ocean surface, the water doesn't move with the wave. Rather, the water moves in a circle called a **wave orbit** (see figure above). The circular motion of the water becomes smaller and smaller with increasing depth, and reaches zero at a depth equal to half the wavelength. This depth is called the **wave base**: the depth of water where orbital wave motion ceases, equal to half the wavelength. A **deep water wave**, by definition, is any wave traveling in water deeper than its wave base. Deep water waves move independently of the sea floor. Their velocity depends entirely on their wavelength and period; waves with longer wavelengths and longer periods travel faster than waves with shorter wavelengths and shorter periods.

Shallow Water Waves

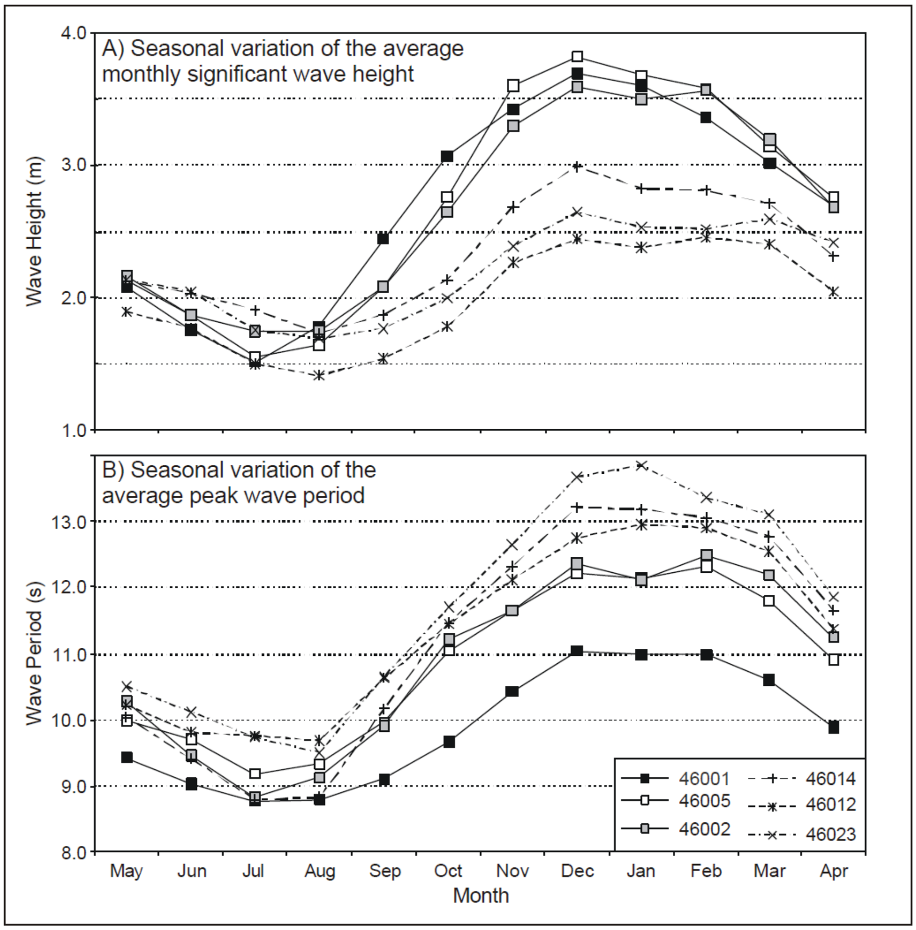
Every ocean wave, if it travels far enough, will eventually encounter shallow water near a beach somewhere. Once a wave enters water where the depth is less than its wave base (i.e. less than half the wavelength), the wave begins to slow down as the orbital motion of the water below the wave makes contact with the sea floor. A **shallow water wave**, by definition, is any wave traveling in water shallower than its wave base. The shallower the water, the slower the wave goes.

The slowing of waves in shallow water has several important effects. The waves that are close to the beach in shallow water slow down more than the waves behind them in deeper water. This causes the waves to "bunch up"; in other words, their wavelengths (L) decrease. The energy of the waves is forced upward so their heights (H) increase (see the figure above). Beyond a critical ratio of wave height to wavelength equal to about 1:7, the waves topple over toward the shore, forming breakers. But even before that happens, the waves feel the effects of slowing in shallow water by undergoing **refraction**, in which waves bend and change direction as they slow down. Refraction happens whenever one part of a wave travels more slowly than another part of the same wave due to differences in water depth.

The one variable that does not change as a wave enters shallow water is the **wave period**. The period remains constant up to the moment that the wave breaks.

Wave Energy and Beach Size

The diagram below illustrates how wave heights (upper graph) and wave periods (lower graph) vary throughout the year in the North Pacific. The different lines represent measurements from separate offshore sensor buoys. Notice that winter months typically have larger waves with longer periods, whereas summer months typically have smaller waves with shorter periods. Because large, long-period waves carry more energy than small, short-period waves, this means more powerful waves hit our beaches in winter than in summer.



Graph A (upper): average monthly significant wave height. Graph B (lower): average monthly peak wave period. From Allan, J.C., and Komar, P.D., 2000. Spatial and Temporal Variation in the Wave Climate of the North Pacific. Report to the Oregon Department of Land Conservation and Development.

Sand moves toward the beach or away from the beach according to the size and power of the waves. The large, long-period storm waves that are common in winter erode sand from the beaches and deposit it in sand bars a few hundred feet offshore. The resulting **winter beach** is typically narrow, eroded, and sometimes covered with large rocks exposed when the sand moved offshore. The small, short-period waves that we get in summer gradually push the sand back from the offshore zone toward the beach. The resulting **summer beach** is typically wide and sandy. The buildup of sand and the increase in beach size from small summer waves is quite slow. In contrast, powerful winter waves from a single storm may erode the beach rapidly.

WAVE TANK EXPERIMENTS

Direct measurement of ocean waves is logistically difficult. But above a certain size, all ocean waves obey the same laws of physics. We can therefore make meaningful observations and measurements by creating waves in laboratory tanks. Naturally, the waves we make will be smaller than actual ocean waves, with smaller **periods, velocities, wavelengths,** and **wave bases**. But as you will see, our experimental waves can be scaled directly up to real ocean waves.

WAVE MOTION: TANK #1

Purpose: *To establish the relationship between wave period (T), wavelength (L), wave base (D), and wave velocity (V) for deep water waves.*

Review questions: write a one-sentence definition of the following terms, based on the information about deep water waves at the start of the exercise.

wavelength (L):

wave period (T):

wave velocity (V):

wave base (D):

deep water wave:

Work with your instructor to make waves of different periods in the tank. Periods will be in seconds (s), distances or depths in centimeters (cm), and velocities in centimeters per second (cm/s).

	beats per minute	period **T** (s)	motion at 2 cm depth? (yes or no)	motion at 10 cm depth?	motion at 20 cm depth?	motion at 30 cm depth?
Wave 1						
Wave 2						
Wave 3						

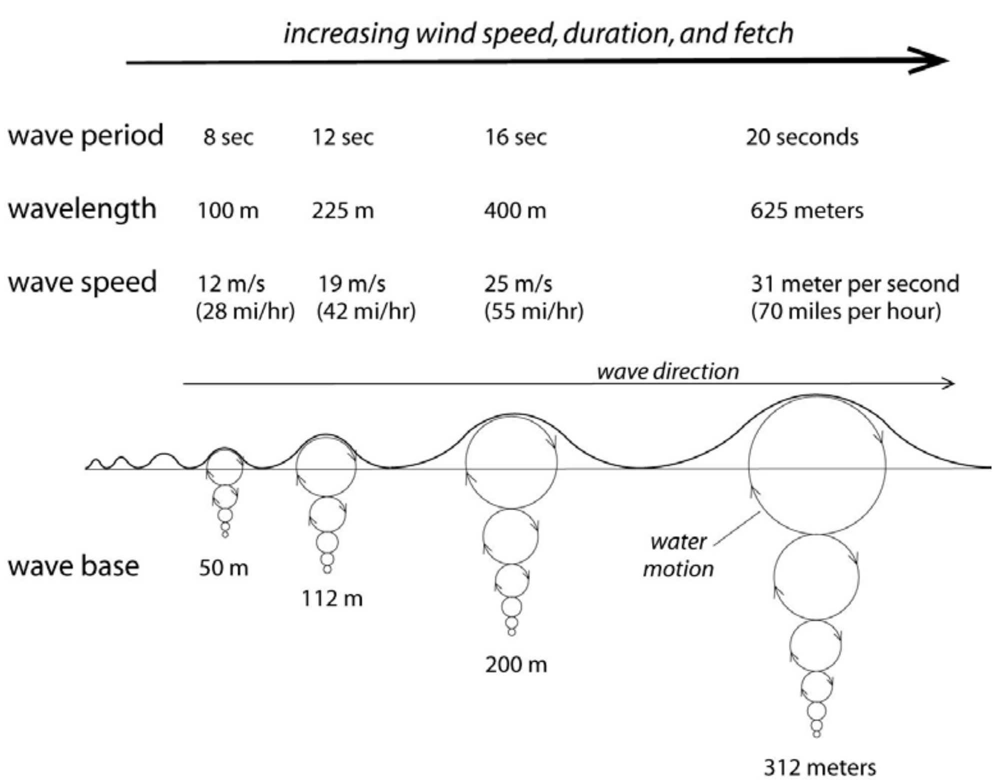
	Measured wavelength **L** (cm)	Wave base **D** (cm) **= L/2**	Wave velocity **V** (cm/s) **= L/T**
Wave 1			
Wave 2			
Wave 3			

1) Do your observations of water motion at various depths for the three waves make sense with your calculated wave bases? Explain.

2) As the **wave period** increases, what happens to the following variables? (*circle the correct answers*)

wavelength	*increases*	*decreases*	*stays the same*
wave base	*increases*	*decreases*	*stays the same*
wave velocity	*increases*	*decreases*	*stays the same*

3) The diagram below shows that as the wind puts more energy into the ocean via increasing **wind speed**, **duration** of the wind, and **fetch** (the distance of water across which the wind blows), ocean waves change in the ways shown. Summarize what the diagram shows, and how it relates to what you observed in the tank.



WAVE SPEED versus WATER DEPTH: TANK #2

Purpose: *To establish the relationship between wave velocity and water depth for shallow water waves.*

Review questions based on the information about <u>shallow water waves</u> at the start of the exercise:

- Define **shallow water wave**, and use the term **wave base** in your answer.

- What happens to the following variables as waves enter shallower and shallower water, like when they approach a beach? (*circle the correct answers*)

wave velocity	*increases*	*decreases*	*stays the same*
wavelength	*increases*	*decreases*	*stays the same*
wave height	*increases*	*decreases*	*stays the same*
wave period	*increases*	*decreases*	*stays the same*

- What is **refraction**, and what causes waves to refract in shallow water?

===========

The theoretical velocity of <u>shallow water waves</u> (**Vs**) is given by the equation:

$$\mathbf{Vs\ (cm/s) = \sqrt{(g \times D)}}$$

Where **g = 980 cm/s** (the Earth's gravitational acceleration), and **D = water depth (cm)**

The equation shows that the velocity of shallow water waves **(Vs)** depends only on water depth **(D)** and gravitational acceleration **(g).** Because **g** is constant, the equation predicts that the shallower the water the slower the wave velocity. You will test this idea and compare your results to theoretical velocities.

1. Fill <u>or</u> drain the tank to the depth assigned to your group. Check the depth (in cm) in the <u>center</u> of the tank. *Do this accurately—small errors matter. Add or remove water as needed to get the depth exact.*
2. Lift one end of the tank and place it on the wooden block. Allow the sloshing water to settle (insert a baffle to help settle the water motion).
3. Have one member of the group ready with a stopwatch.
4. Lift the end of the tank a bit, remove the block, and set (don't drop!) the tank down level to make a wave.
5. Allow the wave to make one round trip before timing. Start the timer when the wave hits one end of the tank. Stop when it returns to that same end (<u>one round-trip</u>). Measure times to the nearest tenth of a second.
6. Repeat <u>three times</u>, writing down each time on the margins of this page. If one of your time measurements turns out to be very different from the others, repeat until you have three measurements that are close.
7. Calculate the <u>average</u> of your three time measurements. Write this value <u>on the board</u> in the correct row for your group.
8. When all the groups are finished, write down the average times for all groups (all rows) in the data table that follows. Then complete the calculations for Measured Velocity and Theoretical Velocity.

Depth **D** (cm)	**Distance** the wave traveled round-trip (cm)	Average **travel time** round-trip (seconds)	**Measured Velocity** (cm/sec) (=distance ÷ travel time)	**Theoretical Velocity** (cm/sec) (from the equation)
1	460 cm			
2	460 cm			
3	460 cm			
4	460 cm			
5	460 cm			
5	460 cm			
4	460 cm			
3	460 cm			
2	460 cm			
1	460 cm			

1) What do the data demonstrate about the relationship between wave velocity and water depth?

2) How well do your measured wave velocities compare to theoretical velocities at the same depths?

3) If for question 2 you answered "they compare closely," or words to that effect, then you can be reasonably confident that the wave equation you used for theoretical velocity will accurately predict wave velocities at greater depths than we used in the tank. Use the equation to calculate the changing velocity of a typical ocean wave as it enters shallowing water on approach to a beach.

Depth in cm	**Velocity in cm/sec** (from the equation)	**Depth in feet** (divide **Depth in cm** by 30.5*)	**Velocity in miles per hour** (divide **Velocity in cm/sec** by 44.7*)
1000			
500			
300			
200			
100			

* 30.5 centimeters equals one foot; 44.7 centimeters per second equals one mile per hour.

4) Good surfers can generally paddle into waves that have slowed down to about 10 miles per hour. At about what water depth, in feet, would surfers be catching waves of that speed?

5) Elite surfers use jet skies to catch larger, faster waves that break in deeper water and are too fast for paddling in. About how fast would a surfer need to be towed to catch a wave about to break in water 30 feet deep?

WAVE ENERGY and BEACH SIZE: TANK #3

Purpose: *To establish the relationship between wave energy and beach growth or beach erosion.*

Review questions based on the information about wave energy and beach size at the start of the exercise.

- In the North Pacific, how does the typical size (height) and period of waves differ between winter and summer? Which waves (winter or summer) have more power and energy when they break on the beach?

- Relating your answer to what you wrote above, summarize how and why Southern California beaches change between winter and summer.

PART 1 – small, short-period waves

Steps:

1. Insert the wave paddle (the board with the white handle) into the **smaller** of the two slots at the end of the tank. Be sure the bottom of the paddle is behind the weights at the bottom of the tank.
2. Set the metronome for **120 beats per minute**.
3. Move the paddle back and forth in the small slot in time with the beats. You will be making waves with a period of 0.5 seconds. Have one member of the group keep the waves going as you answer the questions.

1a) Look at the wavelengths of the waves as they travel from deep water toward the beach. How do the wavelengths change? Why do they change this way? *(Hint: see the description of shallow water waves at the start of the exercise.)*

1b) Compare the <u>wave heights</u> of the waves in deep water to their heights just before they break on the beach. How do the wave heights change? Why do they change this way? *(Hint: see the description of shallow water waves at the start of the exercise.)*

1c) What effect, if any, are these waves having on the sand on the beach? Look closely at the sand to see if you can see any net movement.

1d) Do these waves represent ***summer waves*** or ***winter waves*** ? (circle one)

PART 2 – large, long-period waves

Steps:
1. Now insert the wave paddle into the **larger** of the two slots with the bottom behind the weights as before.
2. Set the metronome for **80 beats per minute.**
3. Move the paddle back and forth in the large slot in time with the beats. You will now be making larger waves with a longer period than before (0.75 seconds). Keep the waves going as you answer the questions.

1a) Look at the wavelengths of the waves as they travel from deep water toward the beach. How do the wavelengths change? Does this match what you saw in Part 1?

1b) Compare the wave heights of the waves in deep water to their heights just before they break on the beach. How do the wave heights change? Does this match what you saw in Part 1?

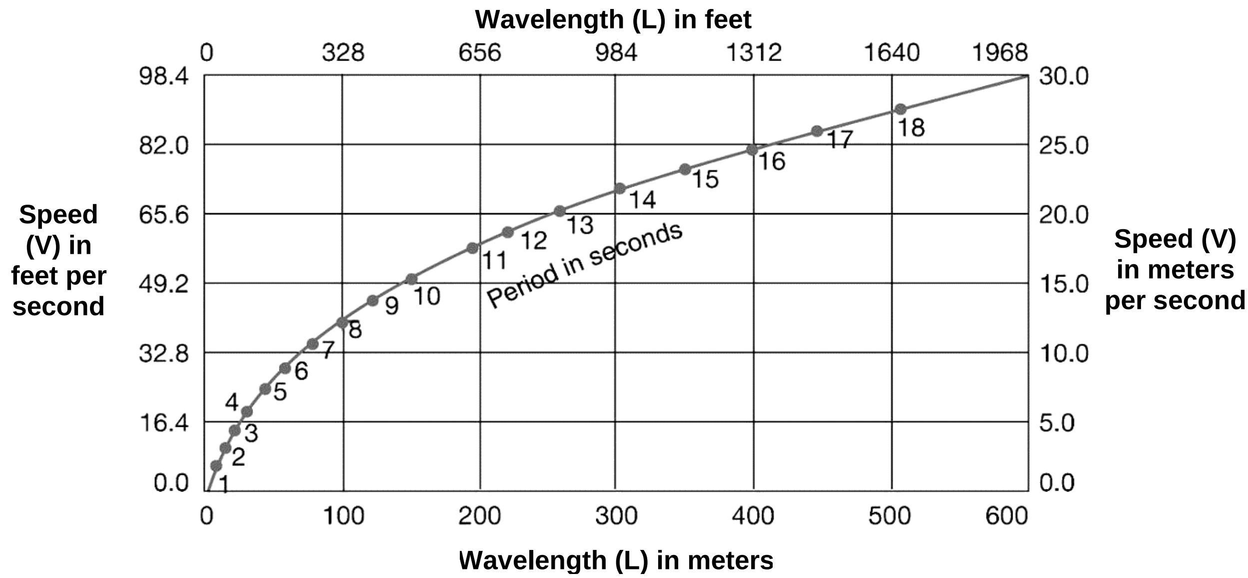
1c) What effect are these waves having on the sand on the beach? Is the sand accumulating on the beach to make it larger, or eroding from the beach to make it smaller?

1d) Do these waves represent ***summer waves*** or ***winter waves*** ? (circle one)

1e) In nature, small summer waves may take months to build up a beach. But powerful waves from a single winter storm can undo all that, removing much of the sand in less than a day. In other words, <u>the growth of beaches by small waves is usually gradual and slow, but their erosion by large waves may be rapid</u>. Relate this to what you observed in the tank in Parts 1 and 2.

WAVES IN SOUTHERN CALIFORNIA WATERS

In the first wave tank experiment today (Wave Motion in Tank #1), you saw how the **period (T), wavelength (L),** and **velocity (V)** all correlate with one another (i.e. they all increase together). The graph below summarizes this relationship for real ocean waves in deep water. Notice that all three variables increase together. In other words, longer period waves have longer wavelengths and faster velocities. This is useful because if we know only *one* of these variables, we can figure out the other two. *(Note: these relationships apply to* ***deep water waves only****. Once waves enter shallow water, their speed and wavelength decrease with decreasing water depth, although their period does not change.)*



Questions

1. A wave has a T of 13 seconds. What is its V in meters per second? ________________
2. A wave has a T of 8 seconds. What is its V in meters per second? ________________
3. A wave has an L of 150 meters. What is its V in meters per second? ________________
4. A wave has an L of 500 meters. What is its V in meters per second? ________________
5. A wave has a V of 10 meters per second. What is its L in meters? ________________
6. A wave has a V of 25 meters per second. What is its L in meters? ________________

Dozens of offshore **sensor buoys** measure the **period (T)** of deep-water waves, allowing us to calculate **L** and **V**. Such buoys can also measure the **height (H)** and **compass direction (D)** of these waves as they approach the Southern California coast.

One of the important sensor buoys for our region is the **CDIP Harvest Buoy** off Point Conception. This buoy gives continuous information on the <u>period, height, and compass direction</u> of deep-water waves approaching the southern California coast.

For the next questions, your instructor will either hand out copies or pull up internet images of wave models for southern California derived from the **CDIP Harvest Buoy**, available at <u>http://www.miracosta.edu/home/kmeldahl/waves</u>

Image 1: NORTHWEST SWELL, DECEMBER 2014

1. What is the **height** (H in feet), **period** (T in seconds) and **compass direction** (D in degrees) of the largest swells detected by the sensor buoy?

Height:_______________ Period: ______________ Compass direction: ______________

2. What is the speed of these waves: in meters per second? (use the graph) _________________

in miles per hour? _________________
(multiply m/sec by 2.24 to get mi/hr)

3. Where along the mainland coast are the largest waves, and what is their height? Why are the waves highest in these areas?

4. What effects do the islands have on the wave heights:

- around the islands themselves?

- on the mainland?

Image 2: SOUTH SWELL, AUGUST 2014

5. What is the **height** (H in feet), **period** (T in seconds) and **compass direction** (D in degrees) of the largest swells detected by the sensor buoy?

Height:______________ Period: ______________ Compass direction: _______________

6. What is the speed of these waves: in meters per second? (use the graph) _________________

in miles per hour? _________________
(multiply m/sec by 2.24 to get mi/hr)

7. Where along the mainland coast are the largest waves, and what is their height? Why are the waves highest in these areas?

8. What effects do the islands have on the wave heights:

- around the islands themselves?

- on the mainland?

Image 3: WAVE CONDITIONS TODAY

9. What is the **height** (H in feet), **period** (T in seconds) and **compass direction** (D in degrees) of the largest swells detected by the sensor buoy?

Height:_______________ Period: ______________ Compass direction: ______________

10. What is the speed of these waves: in meters per second? _________________

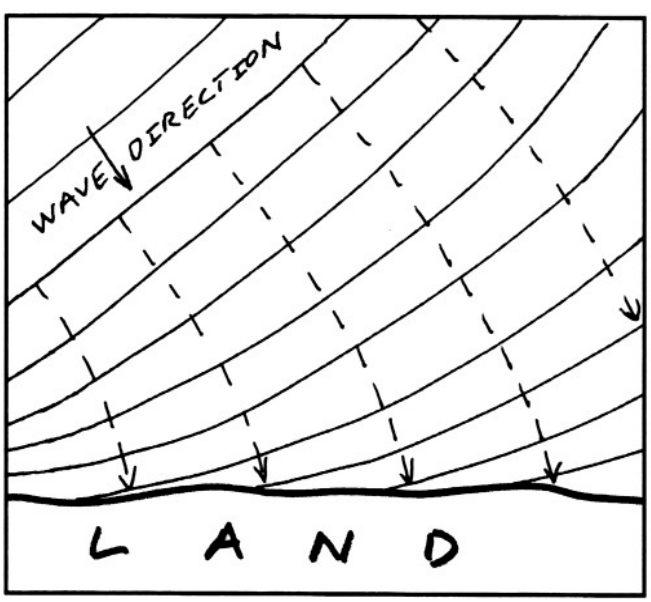
in miles per hour? _________________
(multiply m/sec by 2.24 to get mi/hr)

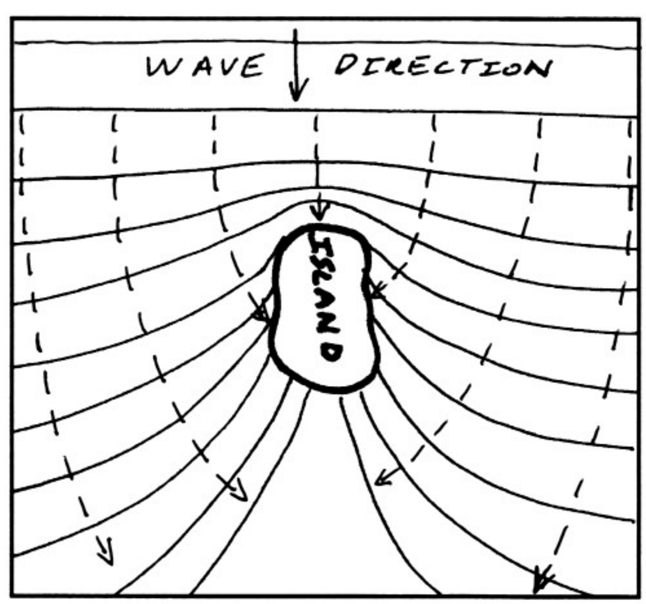
11. Compare and contrast the wave conditions today with those from the previous two images in terms of height, direction, period, and where the largest waves are predicted to be.

PART 2: Shallow Water Wave Refraction

When waves enter water that is shallower than their wave base, they start to slow down as the orbital motion of the wave contacts the ocean floor. As you saw in one of the tank experiments, the shallower the water, the slower the waves go. One result is **refraction**, the process where waves **bend and change direction**. Refraction happens when ***one part of a wave travels more slowly than another part,*** usually because of differences in water depth.

Look at the two examples below, which show how waves will refract as they slow near land. The solid lines represent **wave crests**, as if you were looking down on the ocean from above, and the dashed arrows represent **wave rays**. Notice that wave rays are always drawn perpendicular to wave crests. *(Ask your instructor to explain if you're not sure of the distinction between wave crests and wave rays, and/or if you don't understand why the wave crests and rays shown below look the way that they do.)*





Wave Refraction diagrams. *Use pencil only!!!* Using <u>solid lines</u> to represent **wave crests**, and <u>dashed arrows</u> to represent **wave rays**, complete the sketches below to show how the waves will refract as they approach land. Assume that the closer you are to the shore, the shallower the water and therefore the slower the waves. Use the completed examples on the previous page as a guide. Draw the wave crests first, then draw wave rays <u>perpendicular</u> to the wave crests. ***Note: Your wave crests will not stay straight as they approach shore. Make them bend in a way that accurately shows refraction.***