

## CHAPTER 11

## THE TIDES

### *Objectives*

1. To learn about the regular rise and fall of the tides.
2. To investigate the tides we would expect to find on a non-rotating planet that is covered uniformly with water (equilibrium tidal theory).
3. To study the tides as they actually occur and are made more complex by the presence of continents, ocean basins, and Earth's rotation (dynamic tidal analysis).

### *Key Concepts*

#### **Major Concept (I)**

*The tides rise and fall in response to forces generated by the Sun and the Moon and the rotation of the Earth-Moon system about their common center of mass. The actual pattern of the tides varies from place to place around the world. ç*

Related or supporting concepts:

- The rise and fall of the tides is most evident, and has the greatest impact on society, in shallow coastal waters.
- The vertical distance between high and low tide water levels changes from one place to another around the world.
- Some locations experience a diurnal tide with one high tide and one low tide each day.
- Other areas experience a semidiurnal tide with two high tides and two low tides each day. When the water levels of the two high tides and of the two low tides are unequal, the tidal pattern is called a semidiurnal mixed tide that indicates the presence of combined diurnal and semidiurnal tides.

#### **Major Concept (II)**

*Fluctuating water levels with the passage of the tides are described by a variety of specific terms.*

Related or supporting concepts:

- When an area experiences either a diurnal or a semidiurnal tide with equal maximum and minimum water levels, the highest water level is called high water and the lowest is called low water.
- In a semidiurnal mixed tide, the two high tide water levels are designated higher high water and lower high water. The two low tide water levels are called higher low water and lower low water.
- Figure 11.1 in the text illustrates these definitions and you should look at it to clear up any confusion.
- At any given location, the tides must be monitored over 18.6 years to obtain estimates of the average tide levels at that point and to predict future tides.
- Water depths published on navigation charts are measured from a zero depth reference level called the tidal datum for the area covered by the chart. In regions that experience simple diurnal or uniform semidiurnal tides, the tidal datum corresponds to the long-term average low water level. Where there are mixed semidiurnal tides with two unequal low water levels, the tidal datum is the long-term average lower low water level.
- Minus tides occur when the water level occasionally falls below the tidal datum.
- The rising tide is called a flood tide and the falling tide is called an ebb tide.
- The movement of water with the flood and ebb tides creates tidal currents that reverse direction with the rising and falling water levels. At high and low tide when the tidal currents stop temporarily before reversing their flow, there is a period of slack water.
- If the tide is a progressive type tide in the open ocean, the maximum tidal current in the direction the wave is moving coincides with the crest of the wave, or high tide. The maximum tidal current in the opposite direction coincides with the trough of the wave, or low tide.

**Major Concept (III)**     *The mathematical study of ideal tides behaving in response to the laws of physics is called equilibrium tidal theory. Dynamic tidal analysis is the study of the tides as they occur naturally.*

Related or supporting concepts:

- Equilibrium tidal theory assumes that Earth is smooth and completely covered with water to a constant depth.
- Dynamic tidal analysis studies the tides as they actually occur, influenced by landmasses, the geometry of ocean basins, and Earth's rotation.

**Major Concept (IV)**     *The most influential body in generating the tides is the Moon.*

Related or supporting concepts:

- Let's begin by considering ideal tides generated by the Moon.
- As Earth and the Moon move through space, they rotate around their common center of mass. The center of mass of the Earth-Moon system is at a point roughly 4640 km (2880 mi) from Earth's center on a line joining the centers of the two bodies.
- Two forces act to keep Earth and the Moon at a constant distance from one another. Outward directed centrifugal force ( $F_C$ ), resulting from their rotation around their common center of mass, acts to drive them apart (just as a yo-yo would fly away if you swung it over your head in circles and suddenly let go of the string). The gravitational force of attraction ( $F_G$ ) between Earth and the Moon acts against the centrifugal force and keeps them at a constant distance. Both of these forces are proportional, in part, to the mass of the Moon ( $M$ ) divided by the distance squared between the centers of Earth and the Moon ( $M/R^2$ ).
- Centrifugal force is an apparent force that is present when you judge motion against a rotating frame of reference.
- $F_C$  acting on any particle on Earth is essentially the same, regardless of where that particle is. However,  $F_G$  changes from place to place on Earth's surface.  $F_G$  is largest at a spot on the surface closest to the Moon and it is smallest on the opposite side of Earth farthest from the Moon. These two forces exactly balance at Earth's center but everywhere else they can differ by some small amount.
- The tides are produced by what we can call the tide generating force, or tide raising force ( $F_T$ ). The tide generating force for any given particle is proportional to the difference between the gravitational force of attraction and the centrifugal force acting on the particle:  $F_T = F_G - F_C$ . It can be shown that the tide generating force is proportional, in part, to  $M/R^3$ .
- On the side of Earth closest to the Moon,  $F_G$  is slightly larger than  $F_C$  and the larger gravitational attraction of the Moon will raise a mound of water directly beneath it to form a tidal bulge, or a tidal crest.
- On the opposite side of Earth, farthest from the Moon,  $F_C$  is slightly larger than  $F_G$ , so the centrifugal force will drive water outwards away from the rotating Earth-Moon system. This will raise a second tidal bulge of equal height on the opposite side of Earth from the Moon.
- Another way to explain the tide generating force is to think of Earth constantly accelerating toward the Sun or the Moon in response to their gravitational attraction. The centripetal force is constant and proportional to the average gravitational force acting at Earth's center. The difference between the average gravitational force and the actual gravitational force at individual points on Earth's surface produces the tide-generating force.
- Regions of low water, a tidal trough, are present between the bulges a quarter of the way around the globe from the crests.
- Thus we will see a semidiurnal tide with two high tides and two low tides moving westward around the globe as Earth rotates eastward within the distorted water covering.

- The Moon rotates around Earth in the same direction as Earth rotates on its axis. Because of this it takes 24 hours and 50 minutes for a point on Earth directly below the Moon to make one complete revolution and again be directly beneath the Moon. This period of time is known as the tidal day.
- The progressing lunar semidiurnal tide wave will have a period of 12 hours and 25 minutes and a wavelength of half the circumference of Earth.

**Major Concept (V)**      *The other critical astronomical body that influences the tides is the Sun.*

Related or supporting concepts:

- The Sun also produces a tide generating force in the same way as the Moon. This force produces a solar tide wave.
- We might suspect that the Sun's tide generating force is greater than the Moon's since the mass of the Sun is so large. But remember that we have to divide the mass of the body by its distance from Earth cubed! The tide generating force of the Sun is only 46% as large as that of the Moon because of its enormous distance from Earth.
- While the wavelength of the solar tide wave is the same as the lunar tide wave, the period of the semidiurnal solar tide wave is only 12 hours. This is because Earth makes one complete revolution and brings a point directly beneath the Sun back beneath it in 24 hours.
- The longer period of the lunar tide wave causes it to constantly move eastward relative to the solar tide wave.

**Major Concept (VI)**      *Because the periods of the lunar and solar tides are a little different, the two tides will interfere with one another. This may be constructive or destructive interference, depending on the time (see fig. 11.8). In either case, we must add the two tides together to approximate the actual tide.*

Related or supporting concepts:

- It takes 29.5 days for the Moon to orbit Earth.
- In this period of time the Moon passes through its four phases from new Moon to first quarter, full Moon, and finally third (or last) quarter before the new Moon reappears.
- During the new Moon and full Moon phases the Earth, Moon, and Sun are all aligned. The lunar and solar tides will be in phase and add constructively to produce the spring tide. The spring tide has the largest tidal range or vertical distance between highest and lowest water levels.
- During the quarter phases of the Moon, the lunar and solar tides add destructively. The lunar high tide coincides with the solar low tide. These neap tides have the lowest tidal range.
- In this way, neap tides and spring tides occur alternately at two-week intervals, as fortnightly tides.

**Major Concept (VII)**      *The latitude at which the Moon and Sun are directly overhead varies with time in a regular fashion.*

Related or supporting concepts:

- If the orbital plane of the Moon around Earth and the orbital plane of Earth around the Sun both coincided with the Earth's equatorial plane, the tidal bulges would progress around the equator and at every latitude there would be a simple semidiurnal tide. This tide would have a steadily decreasing range and height with increasing latitude.
- In reality, however, the latitudes at which the Sun and Moon are directly overhead vary both north and south of the equator in a predictable manner.
- The latitude at which the Sun is directly overhead varies between 23.5°N and S. It takes one year for the Sun to complete this cycle.
- The latitude at which the Moon is directly overhead varies between 28.5°N and S. It takes 18.6 years for the Moon to complete this cycle.

- If the Sun and/or Moon are directly overhead at a point that is not on the equator, then the two tidal bulges will be in opposite hemispheres. This will cause points at mid-latitudes to experience diurnal tides with one high and low tide daily. This is called a declinational tide.

**Major Concept (VIII)** *Another variation in the tides is introduced because both the Moon and the Earth have elliptical rather than circular orbits. Consequently, the distances from the Moon and Sun to Earth change, and the tide generating forces change with them.*

Related or supporting concepts:

- Earth is closest to the Sun during the Northern Hemisphere winter.
- Thus, the solar tide is largest during the Northern Hemisphere winter.

**Major Concept (IX)** *The mathematical study of the actual tides as they really occur on Earth is called dynamic tidal analysis.*

Related or supporting concepts:

- The calculated tide generating forces in dynamic tidal analysis are the same as for equilibrium tidal theory.
- The actual tides are quite different, however, because Earth is much more complex than the model used in equilibrium tidal theory.
- The continents create closed ocean basins so the tide wave cannot progress around the globe except at far southern latitudes around Antarctica. Instead, it can reflect off the continental margins and oscillate in these basins as a standing wave.
- The tide wave is reflected from continental edges, refracted by shallow water, and diffracted as it passes through narrow gaps between continents.
- The tides are also influenced by the Coriolis effect because of their long periods and wavelengths.
- The tide wave moves as a shallow-water wave. In the absence of any other factors, it would move as a free wave at a velocity related to the depth of the water of about 200 m/s (400 mi/hr) from east to west.
- Earth rotates from west to east. At some latitudes it rotates at a velocity higher (as great as 463 m/s or 1044 mi/hr at the equator) than the velocity of a free wave. This is more than twice the speed at which the tide can travel as a free shallow-water wave.
- The actual position of the tidal bulge will be determined by the balancing of two opposing forces; frictional contact with Earth will drive the wave further to the east while the gravitational attraction of the Moon will hold it back.
- In this way, the tides move as a forced wave with the tidal bulge slightly in advance, or eastward, of the point on the surface of Earth beneath the orbiting Moon.
- The rotational velocity of Earth's surface decreases with increasing latitude so the tidal bulge is displaced farthest to the east on the equator and is less affected by frictional drag at higher latitudes.
- The frictional drag of the tide wave gradually slows the rotation rate of Earth on its axis, adding 1.5 milliseconds to the length of the day each 100 years.

**Major Concept (X)** *One easy way to see the pattern of movement of the tide wave across and through the ocean basins is to look at a map of cotidal lines indicating the position of the crest of the wave at regular intervals of time, often one hour. This type of illustration is shown in figure 11.11 in the text.*

Related or supporting concepts:

- In some areas the tide wave moves across the ocean basins just as a shallow-water wave would. This occurs in the North Pacific, eastern South Pacific, and the South Atlantic.
- Because the tide wave travels as a shallow-water wave with a very long period:
  - a. water motion extends to the sea floor,
  - b. water particles move in elliptical orbits,

- c. particles move further horizontally than vertically,
- d. particles move for long periods of time in one direction, and
- e. particles can be deflected by the Coriolis effect.

**Major Concept (XI)**     *The reflection of the tide off the edge of a continent can create a rotary standing wave in some parts of the ocean basins.*

Related or supporting concepts:

- Water will naturally flow from an area of high water, or the tidal crest, to an area of low water, or the tidal trough. Because the wavelength of the wave is so long, it takes quite a while for the water to flow from crest to trough and, consequently, the movement is modified by the Coriolis effect.
- In the Northern Hemisphere, the moving water is deflected to the right, causing the tidal crest to rotate counterclockwise around a point where the water level remains constant throughout the tidal cycle. This point, or node, is called the amphidromic point.
- The tidal range varies with position, decreasing to zero at amphidromic points and increasing away from them. The expected tidal range in different regions of the oceans can be estimated from charts displaying lines of equal tidal range, or corange lines as illustrated in figure 11.12.
- Rotating tidal currents are produced as a result of the Coriolis effect acting on water moving in both progressive tide waves and rotary standing tide waves. These tidal currents will rotate clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere.
- Rotary standing waves occur in basins in which the natural period of the basin is close to the period of the tide. The natural period of a closed basin is a function of the depth of the water and the dimensions of the basin. See table 11.1 in the text for examples of the variety of basin depths and dimensions that produce identical natural periods.
- Tide waves in coastal bays or channels reflect at the head of the basin and oscillation of the water surface can occur along the length of the basin. These basins are often so narrow that there is no rotary motion.
- The dimensions of narrow, open-ended basins determine whether they will amplify the tidal range or decrease it. A spectacular example of amplification occurs in the Bay of Fundy in northeast Canada where the tidal range at the mouth of the bay is only 2 m (6.6 ft), while at the head of the bay it is 10.7 m (35 ft)!
- Amplification occurs when the natural period of oscillation of the basin approximately equals the tidal period.

**Major Concept (XII)**     *In some regions, a fast-moving breaking wave called a tidal bore will progress inland through narrow channels, such as the mouths of rivers, with the flood tide.*

Related or supporting concepts:

- If large amplitude tides enter shallow water in narrow, constricted regions, the water can be forced inland at a higher velocity than a simple shallow-water wave would propagate.
- When this happens, the incoming volume of water can form either a single breaking wave or a series of breaking waves.
- The passing tidal bore will create an abrupt change in water level.
- The height of a typical tidal bore is on the order of 1 m but it can be as great as 8 m!

**Major Concept (XIII)**     *The accurate prediction of tides at specific locations requires the combination of astronomical data for the general characteristics of the tide and actual local measurements to account for the complexity added by local conditions.*

Related or supporting concepts:

- Measurements of tides at specific locations are made over periods of years using water level recorders.

- Measurements are taken for as long as 19 years at primary tide stations to evaluate the effect of the 18.6 year cycle in lunar declination.
- These measurements can then be analyzed by a process called harmonic analysis to calculate the many component or partial tides with different amplitudes and periods that combine to form the actual tide.
- The National Ocean Survey (NOS) of the National Oceanic and Atmospheric Administration (NOAA) published annual predicted tide tables covering North and South America, Alaska, Hawaii, and the coast of Asia annually until 1996. With the help of these tables, it was possible to look up the dates, times, and predicted water levels for high and low water at 196 different primary tide stations.
- The tides at other auxiliary stations can be determined by applying compiled corrections for time and height to the data for the primary stations.
- Tide tables are now published by private companies using NOAA data and are available on the internet.

**Major Concept (XIV)** *Accurate estimates of the time, direction, and speed of tidal currents at various locations can also be made in a manner similar to the estimation of the characteristics of the tide wave.*

Related or supporting concepts:

- Detailed knowledge of the characteristics of tidal currents is important in both the open ocean and in coastal waters.
- In the open ocean, the oscillatory circular water motion of tidal currents must be carefully removed to measure the true flow of water in major ocean currents.
- In coastal waters, strong tidal currents can create navigational hazards for boaters.
- Tidal current data is published in a format similar to the tide tables.

**Major Concept (XV)** *Large amounts of energy can potentially be derived from the tides where there are large tidal ranges or narrow channels with fast tidal currents.*

Related or supporting concepts:

- There are two systems for extracting energy from the rise and fall of the tides.
- Both systems require the construction of a dam across a bay or estuary so that water can be held in the bay at high tide.
- During low, or ebb tide there will be a difference in water level on either side of the dam.
- Releasing water from the bay during low tide can drive turbines in the dam and generate electricity.
- A tidal range of at least 7 m (23 ft) is needed for this method to be useful.
- This method only produces energy during a portion of each ebb tide. A sketch of this kind of system is shown in figure 11.17a.
- In a double-action system the dam's gates are opened following the generation of power during ebb tide and the remaining water in the basin is allowed to flow out. The gates are then closed again and some of the remaining water in the basin is pumped out to further lower the water level. The gates are kept closed during the first part of the flood stage cycle and the water level outside of the basin rises. When the water level difference is great enough the flood tide is allowed to flow into the basin through the dam's turbines to generate electricity during the flood tide.
- At the end of the flood tide the dam's gates are closed and water outside of the basin is pumped into the basin to further increase the difference in water level. A sketch of this kind of system is shown in figure 11.17b.
- There are relatively few sites that have been identified around the world with the potential for tidal energy development and they are not all located near population centers where the energy is needed most.
- Power cannot be generated by the tides without environmental consequences.
- The damming of a bay or estuary can alter its natural period of oscillation, interfere with ship travel and port facilities, or alter the salinity by changing its relationship with rivers that empty into it.

### Matching Key Terms with Major Concepts

At the end of the chapter in the textbook is a list of key terms. You should be able to match each of these with one of the previously listed major concepts. To test your ability, try to match the following key terms with the number (I–XV) of the appropriate major concept identified in this section:

cotidal line  
tidal day  
ebb tide  
minus tide  
flood tide  
equilibrium tidal theory

tidal bore  
free wave  
harmonic analysis  
slack water  
corange line  
tidal datum

low water  
diurnal tide  
amphidromic point  
rotary standing tide wave  
dynamic tidal analysis

### Test Your Recall

#### Answer the following questions to test your understanding

#### FILL IN THE BLANK

1. Tides that have two equal high and low water levels each day are called \_\_\_\_\_ tides.
2. In a mixed tide, the greatest height to which the water level reaches is called \_\_\_\_\_.
3. The zero depth reference used for navigational charts is the \_\_\_\_\_.
4. When the water level is falling, the tide is an \_\_\_\_\_ tide.
5. Objects on Earth's surface are subjected to an outward directed \_\_\_\_\_ force as well as a gravitational force.
6. The astronomical body that has the greatest influence on the tides is the \_\_\_\_\_.
7. Gravitational attraction is inversely proportional to distance \_\_\_\_\_ and the tide generating force is inversely proportional to distance \_\_\_\_\_.
8. The period of a diurnal tide is about \_\_\_\_\_ hours and \_\_\_\_\_ minutes.
9. \_\_\_\_\_ tides have the greatest tidal range.
10. The tide generating force of the Sun is only about \_\_\_\_\_ % that of the Moon.
11. Abnormally low tides are called \_\_\_\_\_ tides.
12. A rising tide is called a \_\_\_\_\_ tide.
13. The study of tides as they actually occur is called \_\_\_\_\_.
14. The distance between high and low tide is the tidal \_\_\_\_\_.
15. \_\_\_\_\_ lines mark successive locations of the tide crest at different times.
16. Complex tidal patterns can be separated into components with different \_\_\_\_\_ and \_\_\_\_\_.
17. A tidal pattern with a single high and low water each day is called \_\_\_\_\_.
18. When the tidal current turns from ebb to flood, there is a period of \_\_\_\_\_ water.

19. The Moon moves about \_\_\_\_\_ degrees per day in its orbit around Earth.
20. The Moon's orbit is inclined \_\_\_\_\_ degrees to the Earth-Sun orbit.

#### TRUE - FALSE

1. The crest of the tides moves from north to south across the ocean basins.
2. Some regions experience only one high tide each day while others experience two.
3. A semidiurnal tide has a period that is twice that of a diurnal tide.
4. Equilibrium tidal theory assumes that Earth is covered with a uniform layer of water.
5. In some narrow channels, the tidal currents during slack water can move as fast as 10 knots.
6. Because of its enormous mass, the Sun's tide generating force is the dominant cause of the tides.
7. According to equilibrium tidal theory, the two tidal crests on either side of Earth are of equal height.
8. The tidal day is 24 hours and 25 minutes long.
9. Spring and neap tides alternate with one another and have a period of about two weeks.
10. The Moon's orbit around Earth is elliptical.
11. The tides move as free waves in equatorial regions.
12. Tides move as deep-water waves until they approach continental margins.
13. The highest tidal ranges occur near amphidromic points.
14. Open ocean tidal currents rotate clockwise in the Northern Hemisphere.
15. Rotary standing tides occur in basins in which the natural period of the basin approximates the tidal period.
16. Tidal waves in narrow basins always have a larger range than in open coastal waters.
17. The exact tide can be readily calculated for any area by observing the tides carefully for at least 10 years.
18. The tides can be reflected, refracted, and diffracted.
19. Energy can be extracted from the tides.
20. The tides can be used to generate electrical power during both flood and ebb tide.

#### MULTIPLE CHOICE

1. A tide with two unequal high water marks each tidal cycle is called a
  - a. diurnal tide.
  - b. semidiurnal mixed tide.
  - c. semidiurnal tide.
  - d. rotary standing tide.
  - e. progressive tide.
2. The zero depth reference for navigational charts is also called the
  - a. minus tide.
  - b. high water mark.
  - c. lower low water mark.
  - d. tidal datum.
  - e. higher high water mark
3. Tidal currents will flow during
  - a. flood tide.
  - b. ebb tide.
  - c. slack water.
  - d. all of the above.
  - e. a and b above.
4. The best time to go exploring along the beach to discover new things is
  - a. during a minus tide
  - b. during an ebb tide
  - c. during a spring tide
  - d. at the low water level of a diurnal tide
  - e. at the lower low water level of a semidiurnal tide
5. The \_\_\_\_\_ method of analyzing the tides takes into account the presence of the continents.
  - a. harmonic analysis
  - b. equilibrium tidal theory
  - c. dynamic tidal analysis
  - d. all of the above



- e. none of the above
- 6. The period of a diurnal tide is
  - a. 12 hours.
  - b. 24 hours 50 minutes.
  - c. 12 hours 50 minutes.
  - d. 12 hours 25 minutes.
  - e. 24 hours 25 minutes.
- 7. The tide generating force of the Sun is about \_\_\_\_ % that of the Moon.
  - a. 23
  - b. 46
  - c. 75
  - d. 35
  - e. 18
- 8. Earth and the Moon rotate
  - a. around their center of mass.
  - b. with a period of about 24 hours.
  - c. around the Sun.
  - d. twice per year.
  - e. a and c above.
- 9. The tide generating force of the Sun is relatively large because of its
  - a. distance from Earth.
  - b. great mass.
  - c. tremendous heat.
  - d. sunspots.
  - e. none of the above.
- 10. When the lunar and solar tide waves are 90 degrees out of phase with one another they add
  - a. destructively.
  - b. constructively.
  - c. to produce neap tides.
  - d. a and c above.
  - e. b and c above.
- 11. The crest of the tide wave
  - a. lags behind the Moon due to friction.
  - b. follows directly beneath the Moon.
  - c. is dragged in advance of the Moon by friction with Earth.
  - d. follows directly beneath the Sun.
  - e. moves in advance of the Sun.
- 12. If you observe a diurnal high tide at 2:00 P.M., the next high tide should occur at about what time the next day?
  - a. 2:50 P.M.
  - b. 2:25 A.M.
  - c. 1:10 P.M.
  - d. 3:50 P.M.
  - e. 3:25 A.M.
- 13. The wavelength of a diurnal tide is
  - a. half the circumference of Earth.
  - b. twice the circumference of Earth.
  - c. half that of a semidiurnal tide.
  - d. twice that of a semidiurnal tide.
  - e. a and d above.
- 14. It takes about \_\_\_\_ days for the Moon to orbit Earth.
  - a. 30
  - b. 29.5
  - c. 31.5
  - d. 28
  - e. 32.5

15. The highest latitude at which the Moon is directly overhead is
  - a. 30 degrees.
  - b. 32.5 degrees.
  - c. 23.5 degrees.
  - d. 28.5 degrees.
  - e. 15 degrees.
16. At the equator, a point on the sea floor is rotating to the east at a speed that is
  - a. roughly twice that of a free tide wave.
  - b. about the same as that of a free tide wave.
  - c. roughly half that of a free tide wave.
  - d. the point on the sea floor is stationary.
  - e. none of the above.
17. Lines drawn to mark the location of the tide crest at set time intervals are called
  - a. temporal crest lines.
  - b. cocrest lines.
  - c. cotidal lines.
  - d. isocreasts.
  - e. corange lines.
18. Because the tide wave is a shallow-water wave
  - a. water particle motion extends to the sea floor.
  - b. water particle motion occurs in an elliptical orbit.
  - c. the horizontal component of particle motion exceeds the vertical.
  - d. all of the above.
  - e. none of the above.
19. The rotary standing tide wave in the Northern Hemisphere has a crest that
  - a. moves from west to east across the basin.
  - b. moves counterclockwise.
  - c. moves from east to west across the basin.
  - d. moves clockwise.
  - e. none of the above.
20. The period of the change in declination of the Moon is
  - a. 18.6 years.
  - b. 29.5 days.
  - c. 2 weeks.
  - d. 12.5 years.
  - e. 4.5 months.

### *Visual Aids: Test Your Understanding of the Figures*

1. Take a look at figure 11.6 to see why the period of a semidiurnal tide is longer than 12 hours. Because the Moon moves eastward in its orbit about Earth by only 12 degrees/day, it takes 29.5 days to make one complete revolution.
2. Looking at figure 11.7 can you determine the relative positions of the Earth, Moon, and Sun that would produce the lowest tidal range and the highest tidal range? Why do you think that the full Moon occurs when it is on the opposite side of Earth from the Sun. What about the new Moon?
3. Compare figures 11.11 and 11.12. Locate the amphidromic points in figure 11.11 and then locate these same positions in figure 11.12. What do the corange lines tell you about amphidromic points?

### *Study Problems*

1. Looking at figure 11.2 in the text determine the difference (in feet) in water level at San Diego between:
  - a. higher high water and lower high water
  - b. higher high water and higher low water

- c. higher high water and lower low water
  - d. higher high water and mean tide level
  - e. higher high water and the tidal datum
2. If the length of a solar day is exactly 24 hours and the length of a tidal day is exactly 50 minutes longer, then through how many degrees does the Moon move eastward in its orbit around Earth in a single day?
  3. The tides have such enormous wavelengths that they should travel as shallow-water waves (take another look at Major Concept X above). Given that the acceleration of gravity is  $9.8 \text{ m/s}^2$  and the average depth of the oceans is 4000 meters, what is the expected velocity of the tide wave as a shallow-water wave? We also learned that the velocity of a wave is related to its wavelength and period (see Major Concept IV above). In a semidiurnal tide the wavelength is roughly 20,000 km and the period is 12 hours 25 minutes. Calculate the velocity of the wave in m/s using this method and compare it to the previous answer. What is going on here?

### *Answer Key for Key Terms and Test Your Recall*

#### KEY TERMS

cotidal line (X)  
 tidal day (IV)  
 ebb tide (II)  
 minus tide (II)  
 flood tide (II)  
 equilibrium tidal theory (III)

tidal bore (XII)  
 free wave (IX)  
 harmonic analysis (XIII)  
 slack water (II)  
 corange line (XI)  
 tidal datum (II)

low water (II)  
 diurnal tide (I)  
 amphidromic point (XI)  
 rotary standing tide wave (XI)  
 dynamic tidal analysis (IX)

#### FILL IN THE BLANK

- |                            |                      |                |
|----------------------------|----------------------|----------------|
| 1. semidiurnal             | 2. higher high water | 3. tidal datum |
| 4. ebb                     | 5. centrifugal       | 6. Moon        |
| 7. squared, cubed          | 8. 24, 50            | 9. spring      |
| 10. 46                     | 11. minus            | 12. flood      |
| 13. dynamic tidal analysis | 14. range            | 15. cotidal    |
| 16. magnitudes, periods    | 17. diurnal          | 18. slack      |
| 19. 12                     | 20. 5                |                |

#### TRUE - FALSE

1.F 2.T 3.F 4.T 5.F 6.F 7.T 8.F 9.T 10.T 11.F 12.F 13.F 14.T 15.T 16.F 17.F 18.T 19.T 20.T

#### MULTIPLE CHOICE

1.b 2.d 3.e 4.a 5.c 6.b 7.b 8.e 9.b 10.d 11.c 12.a 13.d 14.b 15.d 16.a 17.c 18.d 19.b 20.a

#### STUDY PROBLEMS

1. a. 2.1 b. 4.8 c. 6.7 d. 3.2 e. 6.4
2. 12.5 degrees
3. a. 198 m/s b. 447 m/s c. The tide wave travels at an unexpectedly high velocity because it is not a free wave but a forced wave.