CHAPTER 5 WATER

Key Concepts

Major Concept (I) *Seawater is a complex mixture of many things. Most of the properties of water are related to the structure of the water molecule.*

Related or supporting concepts:

- Essentially every naturally occurring substance on Earth can be found in seawater, some at high concentrations but most at relatively low concentrations.
- Some of the constituents of seawater include:
  a. dissolved salts,
  b. dissolved gases,
  c. nutrients, and
  d. organic matter.
- The water molecule contains two hydrogen atoms and one oxygen atom. These atoms are arranged in a V-shaped molecule with the hydrogen atoms asymmetrically displaced on one side of the oxygen atom.
- The angle formed by the three atoms is 105° (see fig. 5.1a).
- While the net charge of the molecule is zero, its asymmetrical shape gives it a polarity. There is a positive charge on the side of the molecule with the hydrogen atoms and a negative charge on the other side.
- Water molecules are attracted to each other by their polarity and can form weak bonds called hydrogen bonds. This results in water having more structure than most liquids (see fig. 5.1b).

Major Concept (II) *Water is unique in that it exists in all three states of matter: solid, liquid, and gas within the range of temperature and pressure at Earth's surface. Water will change states of matter by releasing or gaining energy.*

Related or supporting concepts:

- Because of hydrogen bonding between water molecules, it takes a lot of energy, or heat, to make it change from a solid to a liquid or from a liquid to a gas.
- The amount of heat gained or lost in a change of state of matter can be measured in units called calories.
- One calorie is equal to the heat required to raise the temperature of 1 gram of water by 1°C.
- Changes in state result from a gain or loss of energy and the breaking or formation of bonds between molecules.
- Water changes progressively from solid-liquid-water vapor with the addition of heat and the breaking of bonds.

- Water changes progressively from water vapor-liquid-solid with the loss of heat and the formation of bonds.
- Water has a relatively high heat capacity (see table 5.1). This means that it can absorb or lose large amounts of heat with little change in temperature. Another way of looking at it is that it is difficult to raise or lower the temperature of water; it prefers to remain at whatever temperature it is at.
- The latent heat of fusion is the heat required to change 1 gram of pure water from solid to liquid at 0°C. The latent heat of fusion is 80 calories.
- The latent heat of vaporization is the amount of heat required to change 1 gram of pure water from liquid to water vapor at 100°C. This is 540 calories.
- Water can change from a liquid to a gas at lower temperatures but it requires the addition of a greater amount of heat.
- Salt water has a lower freezing temperature and a higher boiling temperature because of the addition of impurities to fresh water. While the actual boiling temperature of seawater is not important in the ocean environment, its freezing point is with the formation of sea ice. Seawater of normal salinity freezes at about -2°C.

Major Concept (III) *The density of water is a function of temperature, salinity, and pressure.*

Related or supporting concepts:

- The density of a substance is its mass per unit volume. The most common units used for density are g/cm^3.
- The density of water generally increases with decreasing temperature. This is because the molecules lose energy and move closer together as they cool.
- The temperature of maximum density ($1\ g/cm^3$) for fresh water is 3.98°C, or about 4°C (see fig. 5.3). Between 4°C and 0°C some of the molecules begin to form a hexagonal crystal structure, pushing individual molecules farther apart and decreasing the density. At 0°C the water will begin to freeze because the water molecules are moving too slowly to break the bonds with neighboring molecules. Freshwater ice has a lower density than liquid water at temperatures below 4°C, hence ice cubes float.
- Density increases with increasing salinity. You can see the effect of temperature and salinity on density in table 5.2.
- The density of average salinity seawater is about 2 to 3 percent greater than fresh water.
- The highest densities would be expected in cold, high salinity water and the lowest densities in warm, low salinity water.
- Increasing pressure forces the water molecules closer together and increases the density. Since pressure increases linearly with depth, density will also. The change in density due to pressure is usually much smaller than changes due to temperature and salinity, so pressure is often ignored in density calculations.
- Pressure increases by approximately 1 atmosphere ($14.7\ lb/in^2$) for every increase of

10 meters in depth (see fig. 5.4).

- The average pressure acting on a column of water in the ocean results in a reduction of ocean depth by about 37 m (121 ft).

Major Concept (IV) *Heat energy can be transmitted by three different processes: conduction, convection, and radiation*

Related or supporting concepts:

- The process of conduction involves the transfer of heat through direct contact. It is a molecular process that is related to the increase in vibration or movement of molecules with an increase in temperature. In general, metals are good conductors while water is a very poor conductor.
- Convection is the movement of a liquid in response to a change in its density with changing temperature. If you raise the temperature of water you will lower its density and it will rise, carrying the heat along with it. Convection in the oceans due to surface currents is a major mechanism for redistributing heat on the planet from equatorial to polar latitudes.
- Radiation is a direct transfer of heat to a body from the heat source. The obvious example of this is the solar radiation that heats Earth. Incoming solar radiation warms the surface waters of the oceans, decreasing the density of the water so that it "floats" on the colder, denser water below.
- Another simple example of radiation is the heat you can feel from a light bulb if you hold your hand near it without touching the bulb.

Major Concept (V) *Incoming solar radiation covers a broad spectrum. A portion of this spectrum is visible light that can be transmitted through water for short distances (see fig. 5.5).*

Related or supporting concepts:

- The intensity of visible light transmitted through water decreases rapidly with increasing depth. This decrease in intensity with depth is called attenuation.
- Roughly 60 percent of incoming light is attenuated in the first meter (3.3 ft), 80 percent in the upper 10 meters (33 ft), 99 percent at a depth of 150 meters (500 ft) in very clear water, and there is essentially no light penetration below 1000 meters (3300 ft).
- The efficiency of light penetration is related to color. Long wavelength red light is absorbed more rapidly than shorter wavelength blues and greens (see fig. 5.6).
- The attenuation of light is due to absorption and scattering by particles in the water. These particles include small sediment grains, single-celled organisms (both plants and animals that live in surface waters), and the water and salt molecules themselves.
- The clearer the water, the greater the penetration and the less the attenuation.

- We usually think of light travelling in a straight line but the path light takes can be bent, or refracted, if it travels from one material into another in which its speed of propagation is different. This is the case for air and water. Figure 5.7 illustrates a simple example of this that you have probably experienced yourself.
- Since the velocity of light in water is affected by its density, the refraction of light in water will vary slightly with changing temperature, salinity, and/or pressure.
- The color of seawater may change from one location to another because of the presence of suspended material in the water, or simply the absorption properties of the water. In some areas the water will appear blue-green because of the absorption of other colors and the presence of microscopic plants with chlorophyll. In coastal regions it may be brownish as a result of high concentrations of suspended sediment. In the open ocean it can appear to be a clear blue color. This usually indicates there is little suspended material of any type in the water.
- A simple instrument to measure light attenuation in surface water is the Secchi disk (see fig. 5.8). The disk may be painted white, or divided into quarters and painted white and black in alternating quarters. It is then lowered into the water until it can no longer be seen. The depth at which it disappears is a function of the amount of suspended matter in the water, or the turbidity. In turbid water it may disappear in 1 meter; in clear water it may be visible as deep as 30 meters.

Major Concept (VI) *Sound propagates through water as a compressional wave whose speed is a function of the temperature, salinity, and pressure of the water.*

Related or supporting concepts:

- Sound travels faster, by a factor of about five, and more efficiently in water than in air.
- The speed of sound in seawater is about 1500 m (5000 ft)/s but it increases with increasing temperature, pressure, and salinity.
- Sound can be reflected, refracted, and transmitted.
- The reflection of sound can be used to determine water depth by knowing the velocity of sound in seawater and timing how long it takes for a pulse of sound generated on a ship to travel down to the bottom and back to the ship once again (see fig. 5.9).
- Precision Depth Recorders are used to determine water depth and sediment thickness (see fig. 5.10).
- Reflected sounds can also be used to determine the location of objects, their approximate size, and distance.
- High intensity sound waves can even penetrate the seafloor sediment and allow marine geologists to determine sediment thickness and layering.
- One system used to detect ships at sea is sonar (SOund Navigation And Ranging).
- The velocity of sound changes with depth as temperature and pressure change. Changes in salinity play only a relatively minor role. Figure 5.12 shows a plot of velocity with depth. You can see a region centered at about 1000 m (3300 ft) where there is a minimum in velocity. This region is called the sofar channel (SOund Fixing

And Ranging).

- Sound will change its direction of travel toward areas of low velocity. Consequently, sound can be preferentially directed into the sofar channel and travel there for long distances with little loss of energy.
- The refraction of sound rays by changes in velocity can create shadow zones where sound will not travel. This is illustrated in figure 5.12. In addition. the bending of sound rays can make it appear as if objects are not where they actually are (see fig. 5.11), just as the refraction of light can make it seem as if objects are somewhere different than their actual location (remember fig. 5.7).
- Recent experiments have used the dependence of sound velocity on temperature to investigate global warming. Careful measurements of the velocity of sound over long distances in the oceans can reveal small changes in water temperatures. One experiment, conducted in Arctic seas, discovered shorter travel times than anticipated, implying water temperatures 0.2 to 0.4°C warmer than just 10 years ago. More study needs to be done before scientists can be sure.

Major Concept (VII) *Water can dissolve almost anything placed in it, given sufficient time.*

Related or supporting concepts:

- The dissolving ability of water is due to its polar nature.
- Water will break soluble compounds into ions which will then be attracted to the water molecules.
- Positively charged ions, or cations, will be attracted to the oxygen side of the water molecule.
- Negatively charged ions, or anions, will be attracted to the side of the water molecule having the hydrogen atoms.
- Ions in water are surrounded by water molecules that separate them from one another (see fig. 5.13).
- I recommend that you take a look at table 5.3 in the chapter to learn more about a variety of other properties of water.

Major Concept (VIII) *Seawater contains almost every naturally occurring substance in it at some concentration. Most substances are present at low concentrations but others can be found at very high concentrations. The quantity of dissolved salts in seawater is called the salinity of the water.*

Related or supporting concepts:

- Salinity is measured in grams of salt per kilogram of water (g/kg), parts per thousand (ppt or $^{o}/_{oo}$), or in Practical Salinity Units (PSU). For most purposes $^{o}/_{oo}$ and PSU are numerically equal.
- There are 11 major constituents, or ions, of seawater that combined represent 99.99

percent of all dissolved material in the water. These are listed in table 5.4.

- The major ions are also called conservative ions.
- Just six of the major constituents account for about 99.4 percent of dissolved material. These ions are chloride, sodium, sulfate, magnesium, calcium, and potassium.
- Anything that is present at a concentration less than 1 part per million is called a trace element.
- The combination of great periods of time and constant motion in the water have mixed it pretty thoroughly. Consequently, the relative abundance of major components is constant regardless of where you take a water sample. In other words, if one sample of seawater has two chloride ions for every one sodium ion, then a second sample of seawater that has been tested to have 30 chloride ions will have 15 sodium ions and there will be no need to actually perform a measurement on the sample to determine that.
- The absolute abundance of major ions can change from location to location. Three different samples of water may have 30, 32, and 28 chloride ions in them. We know from the previous concepts, however, that the samples will have 15, 16, and 14 sodium ions respectively.
- Changes in salinity are primarily the result of changes in the concentration of the water molecule in a given area. Salinity will decrease if fresh water is added through precipitation or runoff and it will increase if the water molecule is removed through evaporation.
- It is relatively difficult to measure salinity, especially while at sea with limited facilities. Because of the constant relative abundance of major ions, however, we only need to measure the concentration of one of them and we can calculate the concentration of the others. The one we choose to measure is the chloride ion. In doing this, we are measuring the chlorinity of the water. Salinity and chlorinity are related by a simple formula:

$$\text{Salinity } (^{o}/_{oo}) = 1.80655 \times \text{Chlorinity } (^{o}/_{oo})$$

- The presence of dissolved ions in water increases its ability to conduct electricity. As the number of dissolved ions increases, the conductivity of the water increases. As a result, it is possible to determine the salinity of seawater by measuring its conductivity using a device called an electrical conductivity meter. Conductivity meters must be corrected for the temperature of the water sample.

Major Concept (IX) *The average ocean salinity is about 35 g/kg or 35 $^{o}/_{oo}$. In general, deep-water salinities are fairly constant but surface-water salinities vary with latitude and proximity to coastlines.*

Related or supporting concepts:

- On average, every kilogram of water will contain about 35 grams of salt dissolved in it.

- Deep water in the oceans tends to have very little variation in salinity.
- The large changes in salinity that occur in the oceans are in surface waters and water near continental margins.
- Surface water salinity in the open ocean is a function of latitude because it is controlled by climate, which depends on latitude. This is shown in figure 5.14.
- Salinity is controlled by patterns of precipitation and evaporation.
- Low salinity surface water is found just north of the equator at about 5° where high precipitation is common. Low salinities are also found at 40° - 50°N and S where there is both high precipitation and low temperatures resulting in fairly low evaporation.
- High surface salinities are found at 25°N and S. These latitudes correspond to desert regions on continents. There is little precipitation and high temperatures evaporate water from the surface and concentrate the salts.
- Figure 5.15 in your text illustrates sea surface salinities over the globe.
- Coastal waters do not necessarily follow this pattern of salinity with latitude. The salinity of coastal water depends more on the presence or absence of runoff from the continent. Large rivers will reduce the coastal salinity.
- Large bodies of water that are semi-isolated from the open ocean, such as the Red Sea, the Persian Gulf, and the Mediterranean Sea can have elevated salinities due to little freshwater input, high evaporation, and little mixing with normal salinity seawater.
- Polar water salinity will vary with the seasons. In the winter, the salinity will be high because as sea ice forms, the salt ions will not be able to fit into the crystalline structure of the ice and will be left behind concentrated in the water. In the summer, the melting ice will return fresh water and the salinity will drop.

Major Concept (X) *The chemical composition of seawater is thought to have remained constant for the last 1.5 billion years despite the continual addition of ions by a variety of processes. This leads us to conclude that as ions are added, an equal number must be removed from seawater to maintain a long term balance.*

Related or supporting concepts:

- Salt ions are added to the oceans by:
  a. rivers and streams,
  b. chemical reactions between seawater and marine sediment,
  c. volcanism on land and in the ocean, and
  d. hydrothermal activity along ridge crests.
- Salts are removed from seawater by:
  a. sea spray along the coast,
  b. periodic evaporation of large bodies of water that have been isolated from the ocean,

c. chemical reactions that form insoluble products,
d. harvesting organisms that concentrate salts,
e. biological processes that extract ions to form hard parts, and
f. the adsorption, or sticking, of ions onto small particles such as clays and fecal pellets.

- Adsorption is considered to be the most important removal process. Ions that are adsorbed onto particles will settle out of the water column with the particle and be incorporated into marine sediment.
- Figure 5.16 illustrates these processes.
- Tectonic processes can elevate old marine sediments above sea level where erosion will release the trapped salt ions and runoff will carry them back to the sea.
- Different ions are removed from seawater at different rates depending on how quickly they react chemically or if organisms use them.
- The average length of time an ion remains in solution is called its residence time.
- Residence times vary dramatically from hundreds to millions of years (see table 5.5). As an example, iron and aluminum have residence times of about 140 and 100 years respectively, while sodium's residence time is about 210 million years. Estimates of the residence time of chloride vary considerably but the shortest time is 100 million years and it may be much longer.

Major Concept (XI) *The survival of plants in the oceans also requires the presence of nutrients. These are analogous to the fertilizers used in agriculture on land. In addition, there are a variety of organic substances present in the water as well.*

Related or supporting concepts:

- The three important nutrients in the oceans are:
  a. nitrogen in the form of nitrate,
  b. phosphorus as phosphate, and
  c. silicon in the form of silicate.
- Nitrogen and phosphorus are used in the production of organic material.
- Silicon is used in the production of hard outer cell walls of small plant-like organisms called diatoms.
- The concentration of nutrients in seawater is fairly low (see table 5.6). They are carried to the oceans by runoff from the land.
- The abundance of these ions in seawater is directly related to biological processes and therefore can be quite variable. Periods of high productivity will deplete their concentration, while in areas of low productivity their concentrations can increase as they are returned to the water by decay and the production of fecal material.
- The relative concentration of nutrient ions does not remain constant in seawater.
- The organic materials that can be found in seawater include:
  a. proteins,

b. carbohydrates,
c. fats (or lipids),
d. vitamins, and
e. hormones.

- These organic materials may be:
  a. used directly by organisms,
  b. be incorporated into seafloor sediments, or
  c. be broken down chemically into inorganic material.

Major Concept (XII) *Another component of seawater is dissolved gases. While there are a variety of different gases present, the two most important are oxygen and carbon dioxide.*

Related or supporting concepts:

- There are three gases that are dissolved in seawater at fairly high concentrations: oxygen, carbon dioxide, and nitrogen (see table 5.7).
- Oxygen and carbon dioxide are very important for marine organisms and their concentrations are modified by biological processes.
- Nitrogen is only used in the oceans by some bacteria.
- The maximum amount of gas that can remain dissolved in seawater without some of it escaping is the saturation value of the gas. Different gases have different saturation values.
- Saturation value is a function of temperature, pressure, and salinity. It will increase with decreasing temperature, increasing pressure, and/or decreasing salinity. Hence, the highest concentrations of dissolved gas are often found in cold, deep water where the pressure is high.
- Oxygen is added to seawater only at or near the surface by:
  a. direct exchange with the atmosphere, and
  b. production by photosynthesis.
- Plants consume carbon dioxide to produce organic material and energy. A by-product of photosynthesis is oxygen.
- Photosynthesis requires sunlight, so it only occurs in the upper 100 m (330 ft) where the sunlight is still intense enough.
- The opposite process is called respiration. Respiration consumes oxygen and organic material (food) and produces carbon dioxide as a by-product.
- Respiration occurs at all depths in the oceans.
- The decay of organic material is called decomposition. This also consumes oxygen and produces carbon dioxide.
- Look at figure 5.17 to see the distribution of oxygen and carbon dioxide with depth. Note that oxygen concentrations are high at the surface where it is produced and below about 800 m (2600 ft) where there is little consumption due to low population densities and sinking surface water replenishes the supply of oxygen. An oxygen

minimum occurs at about 800 m (2600 ft).

- In surface waters the presence of dense populations of plants in some areas can raise the oxygen level above the saturation value by as much as 150 percent. These waters are supersaturated and there will be a loss of oxygen to the atmosphere with wave action.
- In deep isolated basins the oxygen in the water can be removed faster than it is replenished by sinking surface water. Water that is stripped of its oxygen supply is called anoxic.
- Carbon dioxide concentrations are low at the surface where it is removed by photosynthesis. Throughout most of the water column however, carbon dioxide concentrations are fairly constant.

Major Concept (XIII) *Perhaps the most important role carbon dioxide plays is its ability to buffer the pH of seawater, thereby making the oceans a fairly stable environment chemically for marine organisms.*

Related or supporting concepts:

- The pH scale measures the concentration of hydrogen ions in a solution and ranges from 1 to 14. Values between 1 and 6 are said to reflect acidic solutions while values between 8 and 14 are basic. A neutral solution has a pH of 7. Examples of common solutions and their pH values are shown in figure 5.18.
- Carbon dioxide is able to buffer the pH of seawater through a series of chemical reactions that either add or remove hydrogen ions. Buffers make solutions maintain fairly constant pH values.
- The pH of seawater varies between 7.5 and 8.5, with an average value of about 7.8.

Major Concept (XIV) *Seawater can be "mined" for different valuable economic materials as long as they are present in relatively high concentrations and the cost of recovery is reasonable.*

Related or supporting concepts:

- One of the easiest substances to remove from seawater is salt. Salt has been obtained from the oceans for centuries. Currently, about 30 percent of the world's need for salt is satisfied by the oceans.
- In warm climates, seawater is diverted into shallow basins and allowed to evaporate leaving the salt behind. This has been successfully done in California, France, and Puerto Rico.
- In cold climates, seawater is again diverted into shallow basins but allowed to freeze. As the ice forms, the salt ions are excluded from the relatively tight crystal structure and a brine with a high salinity is left behind. The brine can then be heated to remove the last of the water.

- Two other important products taken from seawater are:
    a. magnesium (about 60 percent of the world's supply), and
    b. bromine (about 70 percent of the world's supply).
- Many other very important minerals are present at concentrations that are too low to economically recover at this point in time.
- Perhaps the one substance that has the greatest value in seawater is the water molecule itself.
- Fresh water can be removed from seawater by desalination, or the removal of the salts.
- Unfortunately, desalination is an expensive process. Consequently, it is only used in areas where the need for water is far greater than the supply. In order to conserve our supply of fresh water and make adequate amounts of water available to the planet's increasing population, it will undoubtedly be necessary in the future to increase our use of seawater as a resource.
- There are a variety of ways to remove fresh water from seawater. One simple technique is illustrated in figure 5.20. It uses solar energy to evaporate water from a covered reservoir. The water condenses on the underside of the cover and runs off into collectors along the side. Although this method is inexpensive, it is also inefficient.
- Seawater can also be boiled to generate steam that will then condense as fresh water. This is more efficient but also much more costly.
- Some form of evaporation is used in desalination plants in many areas that have a high demand for fresh water, including Kuwait, Saudi Arabia, Morocco, Malta, Israel, the West Indies, California, and the Florida Keys. About 60 percent of all desalination plants are located on the Arabian Peninsula.
- One particularly interesting way to remove fresh water is by subjecting seawater to high pressure that will force the water molecules through a barrier that will not allow the salt ions to pass. Barriers such as this are called semi-permeable membranes. They will allow some molecules to pass through them while blocking others. This process of generating fresh water is called reverse osmosis.
- The amount of energy required to produce water by reverse osmosis is about one-half that required by evaporation plants.

Key Terms and Related Major Concepts

At the back of the chapter in your book there are a number of key terms. You should be able to find the following terms referenced in the major concept indicated in parentheses.

calories(II)	sonar(VI)	nutrients(XI)
heat capacity(II)	sound shadow zone(VI)	saturation value(XII)
density(III)	sofar channel(VI)	photosynthesis(XII)
conduction(IV)	ion(VII)	respiration(XII)
convection(IV)	salinity(VIII)	supersaturation(XII)
radiation(IV)	major constituent(VIII)	oxygen minimum(XII)
absorption(V)	trace element(VIII)	anoxic(XII)
scattering(V)	conductivity meter(VIII)	buffer(XIII)
attenuation(V)	adsorption(X)	pH(XIII)
refraction(V)	residence time(X)	desalination(XIV)
Secchi disk(V)		reverse osmosis(XIV)

Test Your Understanding With The Following Questions:

FILL IN THE BLANK

1. Fresh water can be forced out of seawater by reverse ______________________.
2. The water molecule is a ________________ molecule because of its shape.
3. Heat is a form of energy that is measured in _________________________.
4. Water will not change temperature easily because of its high _____________ _________________________.
5. Carbon dioxide acts as a ___________________ in the oceans.
6. Salinity can be measured using an instrument called a ___________________________________ _____________.
7. Ocean currents transfer heat from low latitudes to high latitudes by ________________________________.
8. The decrease in intensity of light with depth is called ___________________________________.
9. A ___________________ disk is a simple device for measuring light attenuation.
10. Sound can travel long distances with little loss of energy in the ________________ ______________________.

TRUE - FALSE

1. The water molecule has two oxygen atoms and one hydrogen atom.
2. Water molecules tend to be attracted to each other and cling together.
3. It takes more energy to vaporize water than to melt it.
4. Fresh water will sink to the bottom when it enters the ocean from a river.
5. The freezing of seawater will create salty ice.

6. Seawater tends to be slightly basic.
7. Sound travels along paths that can be bent by changes in velocity in the water.
8. Pressure increases linearly with depth.
9. Light penetration stops completely at a depth of about 100 m.
10. Major constituent ions in seawater have a constant relative abundance.

MULTIPLE CHOICE

1. Fresh water has a maximum density at ______ degrees centigrade.
    a. 0
    b. 4
    c. -2
    d. 5
    e. none of the above
2. The amount of energy required to change water from liquid to vapor is called the:
    a. latent heat of solidification
    b. latent heat of release
    c. latent heat of boiling
    d. latent heat of vaporization
    e. latent heat of liquefaction
3. The addition of salt to water will:
    a. raise the boiling point
    b. lower the boiling point
    c. lower the freezing point
    d. both a and c
    e. both b and c
4. The average salinity of the oceans is about ______ o/oo.
    a. 35
    b. 30
    c. 37
    d. 28
    e. 32
5. The average pH of seawater is about:
    a. 2.5
    b. 7.5
    c. 7.8
    d. 4.6
    e. 9.1
6. Pressure increases by one atmosphere for every increase of ______ m in depth.
    a. 100
    b. 20

c. 50
d. 1000
e. 10

7. About ______ percent of incident light is absorbed in the first meter of seawater.
a. 25
b. 60
c. 15
d. 50
e. 75

8. The velocity of sound in seawater is about _____________ m/s.
a. 500
b. 1000
c. 1500
d. 2000
e. 2500

9. The residence time of iron in seawater is about ___________ years
a. 140
b. 500
c. 10,000
d. 300,000
e. 1,000,000

10. Dissolved oxygen in seawater:
a. is produced by photosynthesis
b. is consumed by respiration and decay
c. can be gained or lost by direct exchange with the atmosphere
d. is least abundant at a depth of about 800 m
e. all of the above

Answer Key for 'Key Terms' and 'Test Your Understanding'

FILL IN THE BLANK

1. osmosis
2. polar
3. calories
4. heat capacity
5. buffer
6. conductivity meter
7. convection
8. attenuation
9. Secchi
10. sofar channel

TRUE - FALSE
1.F 2.T 3.T 4.F 5.F 6.T 7.T 8.T 9.F 10.T

MULTIPLE CHOICE

1.b 2.d 3.d 4.a 5.c 6.e 7.b 8.c 9.a 10.e