

Key Concepts

Major Concept (I) *The oceans are not a single, homogeneous body of water. They actually consist of a number of distinct water masses characterized by different densities due to variations in temperature, salinity, and pressure. There is relatively little mixing between water masses.*

Related or supporting concepts:

- Different water masses can be identified in the oceans on the basis of changes in salinity and/or temperature.
- Changes in salinity, temperature, and pressure cause differences in density, resulting in the layering we see in seawater.
- The individual characteristics of water masses are determined at the surface by such processes as:
 - a. the gain and loss of heat,
 - b. evaporation and precipitation patterns,
 - c. the freezing and thawing of sea ice, and
 - d. surface currents generated by the wind.

Major Concept (II) *Vertical circulation in the oceans is usually the result of density differences in the water. The density of water is a function of salinity, temperature, and pressure.*

Related or supporting concepts:

- Because density is a function of several variables, it is possible to have several different water samples that have identical densities but different salinities and temperatures.
- Density will increase with decreasing temperature, increasing salinity, and increasing pressure or depth.
- Take a look at figure 7.1 to see how the same density water can be generated from different temperatures and salinities. For example, a water sample with a temperature of 5°C and a salinity of 32.9 ppt and a water sample with a temperature of 10°C and a salinity of 33.7 ppt will both have a density of 1.026 g/cm³.
- The upper 100 m (300 ft) or so of the oceans are usually fairly well-mixed by waves and currents. Within this surface mixed layer the density increases only slightly with depth due to increasing pressure.
- From about 100 - 1000 m (300 - 3000 ft) the temperature of the water drops quickly

and the density increases as a result. Depending on where you are in the ocean basins, the salinity in this depth range may increase or decrease, but its influence will not be as great as the falling temperature.

- Below 1000 m the rate of decrease in temperature slows down dramatically. In these deep waters the temperature and salinity will change slowly and the major factor controlling density will be pressure.
- Typical vertical changes in temperature and salinity are shown in figure 7.2.
- Vertical movement of water is the result of changes in the surface density of seawater. Surface density is controlled in large part by climate patterns with latitude.
- In equatorial regions there is a lens of low density surface water at the surface due to warm temperatures and low salinity with the addition of fresh water by precipitation.
- The low density lens at the equator floats on top of higher density water that is generated near 30°N and S where surface temperatures are slightly lower and increased evaporation over precipitation leads to higher salinity.
- At high latitudes, cold temperatures and increased salinity after the formation of sea ice create very high density water that sinks to the sea floor.
- The size of the water mass created in any region is related to the surface area of the region, the density of the water, and how rapidly the water is formed.

Major Concept (III) *Thermohaline circulation is the vertical movement of water caused by density differences that are related to changes in temperature and salinity.*

Related or supporting concepts:

- Vertical motion in the water column is controlled by the stability of the water column. If density increases with increasing depth, the water column is stable and there will be little vertical motion, or mixing.
- If density decreases with depth the water column will be unstable. The denser water will sink, or downwell, and the lighter water will rise, or upwell, until the column is stable again. This vertical motion is called overturn.
- If the density of the water is constant with depth the water column will have neutral density and the water will be easily mixed by waves, currents, and the wind.
- Thermohaline circulation ensures vertical mixing from the sea surface to the sea floor eventually.
- The sinking of high density water in one area will displace an equal volume of lower density water elsewhere that will move upward in the water column.
- The stability of the water column can change seasonally in middle latitudes (see fig. 7.4). In the summer a stable column will form with low density, warm surface water. In the fall, and over the winter, the surface water will cool, increasing in density to the point where it can sink. Strong winter storms can increase the depth of mixing.
- In the open ocean seasonal changes in temperature have a greater impact on circulation than changes in salinity.

- In coastal regions large changes in salinity due to high volumes of freshwater runoff can be more important than temperature changes in regulating density.
- In semi-isolated basins the density of the water may be lowered by freshwater runoff in regions with high precipitation rates or raised by evaporation in dry climates.
- At high latitudes the formation of sea ice in the winter concentrates the salts in the surface water because the large ions do not fit into the crystal structure of the ice. This creates very low temperature, high salinity water that sinks to the sea floor. The densest water on the deep sea floor is formed at the surface in the Weddell Sea of Antarctica.
- In regions of high evaporation, such as the Mediterranean Sea and the Red Sea, warm, saline water is produced with intermediate density that sinks to mid-depths in the open ocean.
- The speed at which water moves varies widely depending on the type of motion. Upwelling and downwelling motion occurs at rates of about 0.1 - 1.5 (0.3 - 5 ft) per day. Fast surface currents move at speeds as great as 1.5 m per second, and deep horizontal thermohaline motion is about 0.01 cm (0.004 in) per second.
- Deep circulation is so slow that water may remain at depth for as much as 100 years before it rises to the surface again.

Major Concept (IV) *Salinity and temperature variations in the oceans are often controlled by thermohaline circulation and surface convergence and divergence patterns.*

Related or supporting concepts:

- Each ocean basin has its own characteristic pattern of water masses.

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THE ATLANTIC OCEAN

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- The general structure of the Atlantic Ocean is illustrated in figure 7.5.
- In the North Atlantic, the deepest water is called North Atlantic deep water. It has average salinity but high density due to very cold temperatures. This water is formed by the convergence of surface water. Surface water from high latitudes moves south and surface water from low latitudes moves north along the coast of North America and the two meet at about 60°N and sink, moving to the south at depth.
- At about 30°N there is a shallow lens of salty, warm water at the surface.
- Water from the Mediterranean Sea flows through the Strait of Gibraltar and sinks to a depth of about 1000 m where it is stable. It flows across the Atlantic Ocean basin and can be identified by its high temperature and salinity.
- In equatorial regions the warm, low density surface water floats on top of Antarctic intermediate water. The Antarctic intermediate water is warmer and less saline than the North Atlantic deep water beneath it.

- Along the Antarctic coast the densest water in the oceans is formed. This water is called Antarctic bottom water. Its temperature is about -0.5°C and it has slightly higher than average salinity.
- The mid-ocean ridge system rises high enough above the surrounding sea floor to act like a dam for the bottom-hugging Antarctic bottom water. Antarctic bottom water is found on the western side of the Atlantic basin.
- North Atlantic deep water moves on top of the denser Antarctic bottom water and comes to the surface near 60°S in the region of Antarctic divergence.
- South Atlantic surface water is simply that portion of the North Atlantic deep water that has surfaced at 60°S and moved toward the equator.

THE ARCTIC OCEAN

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- The Arctic Ocean is connected to the Atlantic Ocean between Spitsbergen and Greenland, and to the Pacific Ocean through the Bering Strait.
- The density of Arctic Ocean water is controlled more by salinity than temperature.
- Arctic Ocean surface water has a low salinity. It is a mixture of low salinity water from the Bering Sea, fresh water runoff from Siberian and Canadian rivers, and the seasonal melting of sea ice.
- Salinity increases with depth where the water is a combination of North Atlantic water and high salinity water created by the seasonal formation of sea ice.
- Water flows out of the Arctic Ocean into the North Atlantic to combine with Gulf Stream water to form North Atlantic deep water.

THE PACIFIC OCEAN

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- The Pacific Ocean lacks a major source of deep water similar to the Atlantic.
- At high latitudes water sinks in relatively small areas of surface convergence and rapidly loses its identity.
- Small amounts of dense water are formed along the Antarctic coast.
- The deep water in the South Pacific comes from the circumpolar current flowing around Antarctica.
- There are surface lenses of warm, saline water in subtropical latitudes in the North and South Pacific.
- At depths below about 2000 m motion in the water is very slow and there are little changes in physical conditions in the water.

THE INDIAN OCEAN

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- The Indian Ocean is restricted to the Southern Hemisphere so there is no equivalent to North Atlantic deep water.
- Bottom water in the Indian Ocean is predominantly from the Antarctic circumpolar

current, as is the case in the Pacific.

- The surface water of the Indian Ocean is warm and has an elevated salinity due to low precipitation and high evaporation.

Major Concept (V) *Special instruments are used to measure physical properties of seawater such as temperature and salinity.*

Related or supporting concepts:

- Until recently, samples of seawater were collected for chemical analysis using a series of bottles lowered to specific depths on a single wire. These were called Nansen bottles (see figure 7.7).
- Nansen bottles are open when they are lowered and closed when hit by a series of triggering weights that travel down segments of the wire between the bottles.
- Today, oceanographers use conductivity-temperature-depth (CTD) sensors to record temperature directly and compute salinity by measuring the electrical conductivity of the water (see figure 7.8). The measurements can be recorded electronically and sent directly to the ship or stored for future data retrieval. CTDs are particularly useful because of the large amounts of data they can collect.
- CTDs can be left in place, suspended from a vessel or buoy, to measure salinity and temperature variations with time.
- Additional sensors can be attached to CTDs to measure variables such as oxygen concentration, nutrients, sound velocity, buoyancy, light transmission, and water transparency.
- CTDs are usually used from a stationary vessel but new models, such as Seasoar (see figure 7.9) can change depth while being towed behind a moving vessel.
- Independent instruments such as the SLOCUM glider (figure 7.10) and floats, or buoys, called profilers (figure 7.11) are able to monitor water properties in different areas and at different depths. They are designed to surface periodically and transmit their data to a ship or satellite.
- While newer electronic instruments can collect data more quickly, they still must be calibrated using results from older instruments like reversing thermometers and water samples collected with reversing bottles.

Major Concept (VI) *Surface currents in the oceans are driven by winds. The major surface circulation patterns at sea are the result of the prevailing winds in the atmosphere.*

Related or supporting concepts:

- Prevailing winds in the atmosphere drive surface currents in the oceans in predictable patterns.
- Large circular surface currents called gyres dominate the wind-driven surface

circulation in each hemisphere.

- The major gyres in the Northern Hemisphere rotate clockwise while in the Southern Hemisphere they rotate counterclockwise.
- Imagine that the near surface water is actually composed of a number of thin layers lying on top of one another, each layer numbered with layer number 1 being at the surface. The blowing wind will drive the water in layer number 1. The water in layer number 2 will be driven by the motion of layer number 1. In a similar manner, each deeper layer is driven by the one above it.
- Because the friction between the wind and layer number 1 is relatively small, and the friction between water layers is also small, the direction in which each layer moves will be influenced by the Coriolis effect.
- The surface water will be deflected at about 45° to the right of the direction of the wind. Each deeper layer of water will also be deflected to the right of the layer above it.
- With increasing depth there will be some loss of energy so the velocity of the motion will decrease.
- The net result is that the blowing wind will create motion in the water that decreases in velocity with depth and is deflected farther to the right (in the Northern Hemisphere) or to the left (in the Southern Hemisphere). If you could see this motion it would look like a spiral extending to a depth of about 150 m before motion stopped. This is called the Ekman spiral (see fig. 7.12).
- At the base of the Ekman spiral the direction in which the water moves is actually opposite the direction in which the wind blows!
- The average direction in which water is being transported over the entire depth of the spiral is 90° to the right of the wind in the Northern Hemisphere and to the left of the wind in the Southern Hemisphere. This is called Ekman transport.

Major Concept (VII) *The large gyres that dominate surface circulation isolate lenses of low density water in their centers. In addition, currents on the western side of Northern Hemisphere ocean basins tend to be narrower and stronger than their counterparts on the eastern side.*

Related or supporting concepts:

- As the prevailing winds drive the large surface gyres, water is directed inward to the center of the gyres by Ekman transport.
- Ekman transport creates an elevated sea surface due to the piling up of the water. The difference in elevation is as much as 1 m (3 ft) or more.
- Gravity causes water to flow down the slopes of this elevated mound. The water will be deflected by the Coriolis effect and when everything is in balance there will be a circular rotation of water around the mound. Take a look at figure 7.14 to see an illustration of this phenomenon.
- The central water of surface gyres is isolated in the interior of the gyres.

- The surface currents generated by the wind travel at speeds that are about 0.01 times the average wind speed. Typical speeds are on the order of 0.1 - 0.5 m/s (0.3 - 1.5 ft/s or 0.25 - 1 knot).
- Current velocity will increase when large volumes of water are forced through narrow straits. An example would be the Florida Current moving out of the Gulf of Mexico and north along the coast of Florida. It moves at a speed of about 1.5 m/s.
- Major currents transport huge volumes of water. The volumes are so great that they are measured in units called Sverdrups. One Sverdrup = 1 million m³/s. The flow of the Gulf Stream is about 55 Sverdrups.
- Currents on the western side of Northern Hemisphere ocean basins are stronger than they are on the eastern side. This is known as western intensification and it is related to:
 - a. the Coriolis effect,
 - b. friction between the currents and land, and
 - c. the piling up of water on the western side of the basin by the trade winds.
- Western intensification is most pronounced in the Gulf Stream and Kuroshio currents in the Northern Hemisphere.
- Western intensification is not as pronounced in the Southern Hemisphere because the eastern currents are strengthened by water from the West Wind Drift that is deflected northward by the continents.

Major Concept (VIII) *The major surface currents are often given specific names to identify them. Figure 7.15 in the text locates the most important surface currents.*

Related or supporting concepts:

THE PACIFIC OCEAN

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- In the North Pacific the surface circulation is dominated by a clockwise rotating gyre formed by:
 - a. the North Equatorial Current,
 - b. the Kuroshio Current,
 - c. the North Pacific Current, and
 - d. the California Current.

This gyre is driven by the northeast trade winds and the westerlies.
- Further north in the North Pacific there is a smaller counterclockwise rotating gyre formed by:
 - a. the North Pacific Current,
 - b. the Alaska Current, and
 - c. the Oyashio Current.
- In the South Pacific the surface circulation is dominated by a counterclockwise rotating gyre formed by:

- a. the South Equatorial Current,
- b. the East Australia Current,
- c. the northern edge of the West Wind Drift, and
- d. the Peru Current.

This gyre is derived by the southeast trade winds and the westerlies.

- The North and South Pacific gyres lie on either side of 5°N due to the unequal heating of the surface between the two hemispheres.
- Between these gyres is the Equatorial Counter Current flowing from west to east, returning some of the water driven toward the western Pacific.
- Figure 7.15 illustrates the characteristics of the average surface current movement over relatively long periods of time. Scientists have now started to investigate the existence of twenty to thirty year current and climate cycles in the Northeast Pacific, known as the Pacific Decadal Oscillation or PDO.

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THE ATLANTIC OCEAN

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- In the North Atlantic there is a similar clockwise rotating gyre formed by:
 - a. the North Equatorial Current,
 - b. the Gulf Stream,
 - c. the North Atlantic Current, and
 - d. the Canary Current.
- In the South Atlantic the counterclockwise rotating gyre is formed by:
 - a. the South Equatorial Current,
 - b. the Brazil Current,
 - c. the northern edge of the West Wind Drift, and
 - d. the Benguela Current.
- The Atlantic gyres are also displaced north of the equator by a small distance.
- There is a weak Equatorial Counter Current in the Atlantic on the eastern side of the ocean basin. On the western side there is a net flow of water from the Southern Hemisphere to the Northern at the surface.
- Recent studies have found evidence of cyclical changes in circulation in the North Atlantic called the North Atlantic Oscillation. This is similar to the Pacific Decadal Oscillation.
- The North Atlantic Oscillation is characterized by pools of warm and cool surface water with life spans of four to ten years that circle the North Atlantic. Cold, low salinity surface water appears to produce colder than average winters in northern Europe and North America. It also affects the rate of formation of North Atlantic deep water.

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THE ARCTIC OCEAN

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- In the Arctic Ocean the polar easterlies drive a large clockwise gyre (see fig. 7.16).

- A small amount of water enters the Arctic Ocean from the Pacific Ocean through the Bering Strait.
- Arctic Ocean water exits north of Greenland as the East Greenland Current and flows into the North Atlantic.
- The West Greenland Current joins the Labrador Current to carry water south along the Canadian coast.
- Most Atlantic water flows east above Norway and Finland and then across Siberia's Arctic coast.

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THE INDIAN OCEAN

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- Because the Indian Ocean is primarily a Southern Hemisphere ocean, its surface circulation is dominated by a counterclockwise rotating gyre formed by:
 - a. the South Equatorial Current,
 - b. the Agulhas Current,
 - c. the northern edge of the West Wind Drift, and
 - d. the West Australian Current.
- The waters north of the equator in the Indian Ocean move to the east in the summer and to the west in the winter with the seasonal changes in monsoon winds.
- Without any continents to block its flow the West Wind Drift is the only continuous current flowing around the globe. It moves from west to east around Antarctica.
- Other major surface currents can be seen in figure 7.15.

Major Concept (IX) *Zones of open ocean surface convergence and divergence mark regions of sinking and rising water respectively.*

Related or supporting concepts:

- Thermohaline circulation and wind driven surface currents combine to create areas of surface convergence and divergence in the open ocean.
- Sinking surface water is replaced by lower density water that flows into the region of sinking. This is called surface convergence.
- Low density water that rises to the surface will spread out and move away in a process called surface divergence.
- Other areas of surface convergence and divergence are caused by blowing wind along continental margins and in the open ocean.
- Figure 7.17 illustrates the locations of permanent zones of surface convergence and divergence.
- Surface convergence in the open ocean occurs at:
 - a. 0° in the tropical convergence beneath the doldrums,
 - b. 30°- 40°N and S in the subtropical convergences,

- c. 50°N and S in the Arctic and Antarctic convergences, and
 - d. the coastal Antarctic convergence at 60°S .
- Sinking water in zones of convergence carries oxygen from the surface to greater depth.
- Surface divergence in the open ocean occurs in three areas:
 - a. on either side of the tropical convergence, and
 - b. in the Antarctic divergence.
- In regions of surface divergence deep water comes to the surface carrying high concentrations of nutrients and dissolved gas that promote high levels of biological productivity.
- The velocity of vertically moving water is quite low (0.1 - 1.5 m/day) compared to the velocity of wind-driven surface currents (1.5 m/s).
- Thermohaline circulation of deep bottom water is very slow. Typical velocities are about 0.01 cm/s.
- Convergences and divergences also produce water mixing.
- Converging surface water masses mix to produce a new water mass of intermediate salinity and temperature that have slightly greater density and sink to intermediate levels where they then move out horizontally and eventually rise to the surface again elsewhere.
- Thermohaline circulation and wind-driven surface currents are very closely related and of roughly equal importance.
- The exact nature of ocean circulation changes with time. Over long time scales, changes in the configuration of the continents creates changes in the shapes of ocean basins. Over shorter time scales, changes in climate from glacial to interglacial periods will influence circulation.
- Present day circulation of surface and deep water is shown in figure 7.18.

Major Concept (X) *Regions of coastal upwelling and downwelling can be created by prevailing wind directions.*

Related or supporting concepts:

- Upwelling and downwelling can also be generated by winds causing Ekman transport of water away from or toward continental margins respectively.
- Regions of upwelling often have high biological productivity as cold, deep water rich in dissolved gas and nutrients comes to the surface to support plant growth.
- Regions of nearly permanent upwelling are found on the eastern sides of ocean basins. These areas are very rich fishing grounds.
- Along some coasts seasonal changes in wind direction cause alternating upwelling and downwelling. An example would be the northwest coast of the United States, as illustrated in figure 7.19.
- Zones of convergence and divergence increase the mixing of different water masses to

create new water masses of intermediate temperature and salinity.

Major Concept (XI) *Currents do not generally flow in smooth curves or straight lines. Current paths will meander and sometimes close on themselves to form eddies.*

Related or supporting concepts:

- When currents twist and close on themselves they can trap water from one side of the current on the opposite side. An excellent example of this is shown in figures 7.20 and 7.21 in the case of the Gulf Stream.
- These trapped parcels of water will rotate and retain their individual characteristics for weeks or months with little mixing. They are called eddies.
- Eddies can form at the surface or at depth.
- Eddies can vary from tens to hundreds of kilometers in diameter.

Major Concept (XII) *Currents can be measured using either stationary instruments or instruments designed to float and move along with the current.*

Related or supporting concepts:

- Moving water at any depth can be monitored using specially designed buoys or floats whose density can be changed to keep the instrument at a specific depth. Data from the instrument can then be relayed to a ship.
- Surface buoys can also be tracked with satellites or photography to determine speed and direction of travel (see fig. 7.22).
- Surface currents can be seen more readily if a dye is released into them.
- Older style current meters record water velocity with a rotor and direction with a vane (see fig. 7.23a). The current meter is often submerged to remove the effect of wind and waves (see fig. 7.24a).
- Modern current meters measure current speed and direction using sound waves (See fig. 7.23b). Narrow frequency sound beams are emitted in four directions. The sound waves will reflect off of small particles carried by the currents. If the water is moving away from the instrument the frequency of the echo will be lower than the original frequency. If the water is moving toward the instrument the frequency of the echo will be higher than the original frequency. This is known as the Doppler Effect. To determine current direction and speed the measurements from all four directions are combined and compared to an internal compass.

Major Concept (XIII) *There is a tremendous amount of energy available in the oceans due to the high heat capacity and the constant motion of the water.*

Related or supporting concepts:

- The oceans are heated from above by incoming solar radiation. Consequently, surface water is appreciably warmer than water at depth.
- The extraction of thermal energy from the water is the objective of OTEC (Ocean Thermal Energy Conversion) systems (fig. 7.25). There are two types of OTEC systems, closed cycle and open cycle.
- OTEC systems depend on the difference in temperature between surface water and water at a depth of 600 - 1000 m (2000 - 3300 ft).
- In the closed OTEC system, heat is extracted from warm surface water to vaporize a working fluid like ammonia or freon. This vapor is stored under pressure and used to drive a turbine. Cold deep water is pumped to condense the vapor and the process is repeated.
- In the open OTEC system, warm surface water is placed in a low pressure chamber where a small fraction of it will be converted to steam to drive a turbine and generate power. The steam will then be condensed through contact with cold water pumped from below. The condensed water will be fresh water.
- In order to generate more power than the amount required to run the system there must be a temperature difference in the water of at least 20°C. The best location for an OTEC plant would be somewhere between about 25°N and S latitude where seawater temperatures over depth average 22°C.
- Engineers studying the efficiency of OTEC systems estimate that they would produce an amount of usable power per square km of ocean surface equal to about 0.07% of the average absorbed solar energy over that area.
- There may be unknown side effects related to pumping cold deep water to the surface. This water is typically enriched in nutrients which would be liberated in the nutrient-poor tropical surface water.
- There is a land-based open-system OTEC plant in Hawaii that produces useable energy and desalinated water. The nutrient -rich deep water is used in a variety of aquaculture projects and as a coolant to provide air-conditioning at the plant.
- Surface currents also represent huge reservoirs of energy that could be harnessed.
- One method that has been proposed would be to anchor large turbines in the path of a current. The moving water would turn the turbines and generate electricity just as hydroelectric power plants do at dams.
- There are some problems associated with extracting energy from currents, including:
 - a. most currents move too slowly,
 - b. many currents are not located near where the energy would be needed the most,
and
 - c. the cost of any such product is currently greater than the value of the energy.

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.

overturn(III)	Ekman spiral(VI)
thermohaline circulation(III)	Ekman transport(VI,VII)
convergence(IX)	gyre(VI)
divergence(IX)	western intensification(VII)
tropical convergence(IX)	downwelling(III, X)
subtropical convergence(IX)	upwelling(III, X)
North Atlantic deep water(IV)	eddy(XI)
Antarctic intermediate water(IV)	current meter(XII)
Antarctic bottom water(IV)	ocean thermal energy conversion(XIII)
South Atlantic surface water(IV)	

Test Your Understanding With The Following Questions:

FILL IN THE BLANK

1. Wind-driven surface circulation is dominated by large _____.
2. Water masses are differentiated from one another by their _____.
3. The sinking of dense water that lies above lower density water is called _____.
4. Vertical circulation driven by density differences is called _____ circulation.
5. Currents can twist and pinch off rings of water called _____.
6. The densest water in the oceans is created around _____.
7. North Atlantic deep water flows toward the _____.
8. The movement of the water caused by the blowing wind as a function of depth is called the _____.
9. The phenomena of stronger currents in the western North Pacific than in the eastern North Pacific is called _____.
10. Closed OTEC systems utilize a fluid that will vaporize in contact with warm water, like ammonia or _____.

TRUE - FALSE

1. Many combinations of salinity and temperature can produce the same density in seawater.
2. Surface salinity is often related to changing climate patterns with latitude.
3. The equator is so hot that evaporation leads to high salinities at the surface.

4. Steadily increasing density with increasing depth creates an unstable water column.
5. Zones of upwelling are often regions of high biological productivity.
6. Vertical motion in the water column often is much faster than horizontal surface currents.
7. The formation of sea ice can increase the salinity of the water around it.
8. There is no source for dense bottom water in the North Pacific analogous to the North Atlantic deep water.
9. Ekman transport mounds water into the center of gyres.
10. The sea surface is elevated by about 10 m in the center of gyres.

MULTIPLE CHOICE

1. Changes in the density of seawater are caused by changes in:
 - a. temperature
 - b. pressure
 - c. salinity
 - d. all of the above
 - e. a and c
2. The density of seawater increases with:
 - a. increasing salinity
 - b. increasing temperature
 - c. decreasing pressure
 - d. decreasing temperature
 - e. a and d
3. The well-mixed surface layer in the oceans extends to a depth of about:
 - a. 100 m
 - b. 500 m
 - c. 1000 m
 - d. 10 m
 - e. 50 m
4. Water moving horizontally at the surface toward a region of sinking is called:
 - a. upwelling
 - b. divergence
 - c. convergence
 - d. thermohaline
 - e. chaotic
5. The water with the second highest density is:
 - a. Antarctic bottom water
 - b. North Atlantic deep water
 - c. Mediterranean water
 - d. South Atlantic deep water
 - e. Caribbean heavy water
6. The deflection of the surface water is at an angle of _____ to the _____ of the direction of the wind in the Southern Hemisphere.
 - a. 30°, right

- b. 45°, right
 - c. 90°, left
 - d. 45°, left
 - e. 30°, left
7. Blowing wind will generate motion in the water to a depth of about:
- a. 1 km
 - b. 150 m
 - c. 50 m
 - d. 1000 m
 - e. 10 m
8. The current that circles the globe around Antarctica is called:
- a. West Wind Drift
 - b. southern circumpolar current
 - c. Antarctic current
 - d. Agulhas current
 - e. Kuroshio current
9. Deep water is often rich in:
- a. dissolved gas
 - b. plant life
 - c. nutrients
 - d. all of the above
 - e. a and c
10. OTEC systems require water temperature differences of at least _____ °C.
- a. 5
 - b. 10
 - c. 20
 - d. 30
 - e. 35

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

FILL IN THE BLANK

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|-----------------------------|----------------------------|
| 1. gyres | 6. Antarctica |
| 2. density | 7. south, or equator |
| 3. overturn, or downwelling | 8. Ekman spiral |
| 4. thermohaline | 9. western intensification |
| 5. eddies | 10. freon |

TRUE - FALSE

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

MULTIPLE CHOICE

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