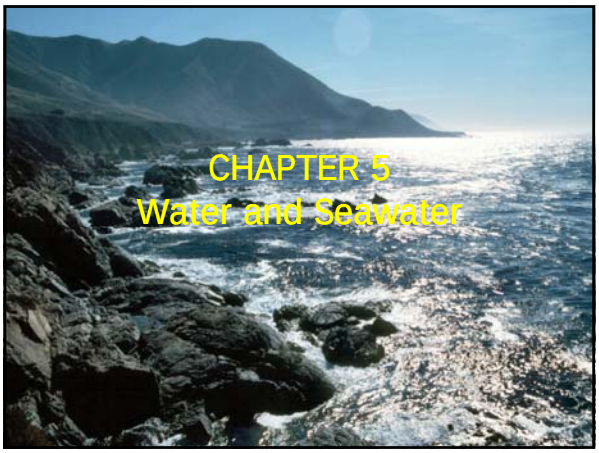
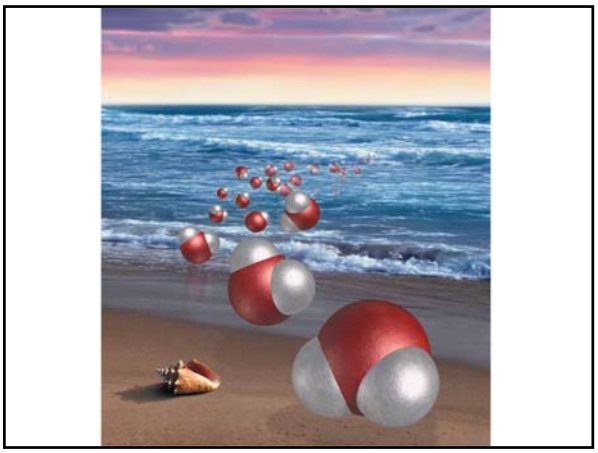




Chapter Overview

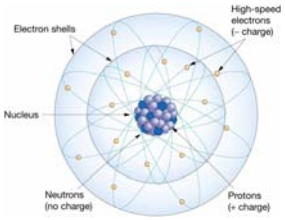
- Water has many unique thermal and dissolving properties.
- Seawater is mostly water molecules but has dissolved substances.
- Ocean water salinity, temperature, and density vary with depth.

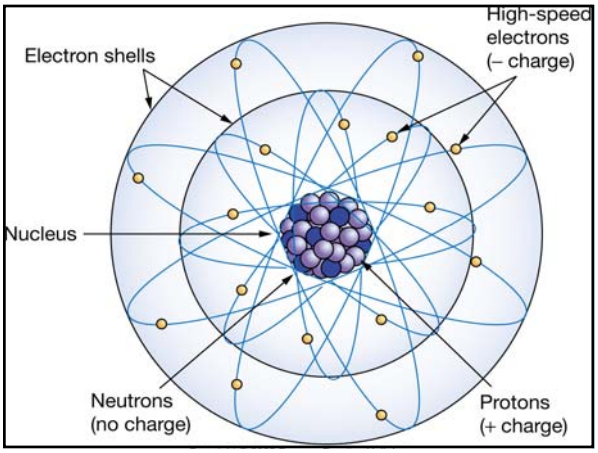
Water on Earth

- Presence of water on Earth makes life possible.
- Organisms are mostly water.

Atomic Structure

- Atoms – building blocks of all matter
- Subatomic particles
  - Protons
  - Neutrons
  - Electrons
- Number of protons distinguishes chemical elements



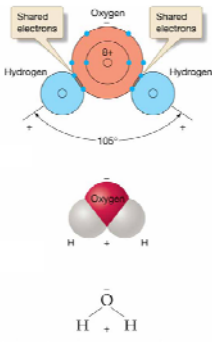


Molecules

- Molecule
  - Two or more atoms held together by shared electrons
  - Smallest form of a substance

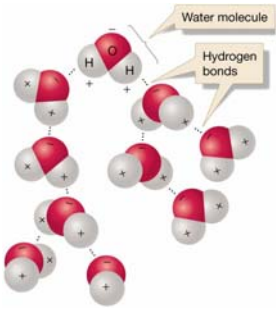
Water molecule

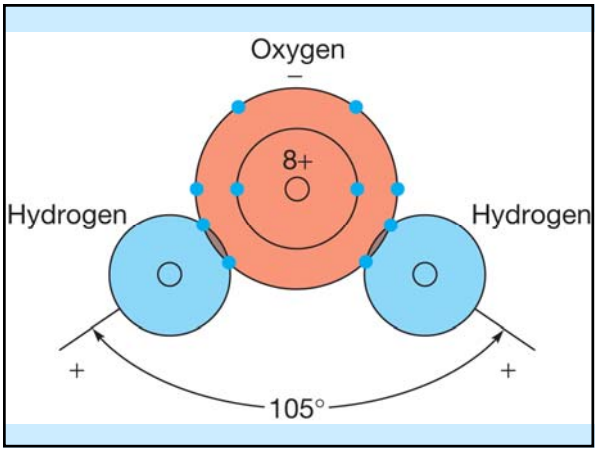
- Strong covalent bonds between two hydrogen (H) and one oxygen (O) atoms
- Both H atoms on same side of O atom
  - Bent molecule shape gives water its unique properties
- Dipolar



Hydrogen Bonding

- Polarity means small negative charge at O end
- Small positive charge at H end
- Attraction between positive and negative ends of water molecules to each other or other ions



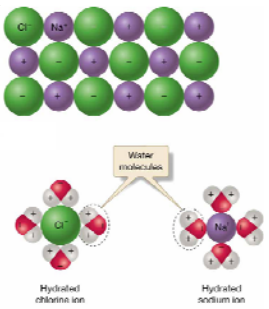


Hydrogen Bonding

- Hydrogen bonds are weaker than covalent bonds but still strong enough to contribute to
  - Cohesion – molecules sticking together
  - High water surface tension
  - High solubility of chemical compounds in water
  - Unusual thermal properties of water
  - Unusual density of water

Water as Solvent

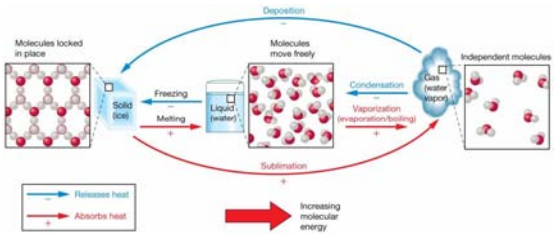
- Water molecules stick to other polar molecules.
- Electrostatic attraction produces ionic bond.
- Water can dissolve almost anything – universal solvent



Water's Thermal Properties

- Water is solid, liquid, and gas at Earth's surface.
- Water influences Earth's heat budget.

Water's Three States of Matter



Heat, Temperature, and Changes of State

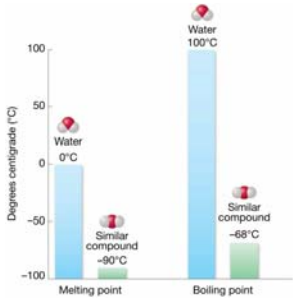
- Van der Waals forces
  - Weak interactions when molecules are close together
- Energy must be added for molecules to overcome attractions.

Heat and Temperature

- Heat – transfer of both kinetic and potential energy from one object to another due to temperature differences
- Temperature – average kinetic energy of molecules in a substance
- Calorie is the amount of heat needed to raise the temperature of 1 gram of water by 1°C.

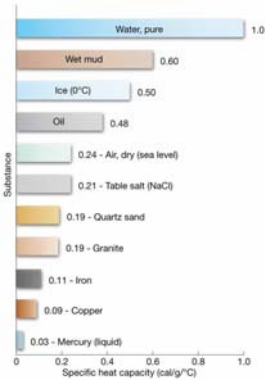
Freezing and Boiling Points

- Freezing point = melting point: 0°C (32°F)
- Boiling point = condensation point: 100°C (212°F)
- Freezing and boiling points of water unusually high



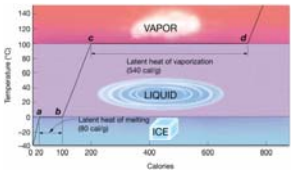
Water's Heat Capacity and Specific Heat

- Heat Capacity – amount of heat required to raise the temperature of 1 gram of any substance by 1°C
- Water has a high heat capacity – can take in or lose much heat without changing temperature
- Specific Heat – heat capacity per unit mass



Latent Heat

- Water has high latent heats
  - Heat absorbed or released during change of state
- Water's latent heat related to its high heat capacity



Latent Heat

- Latent Heat of Melting
  - Energy needed to break intermolecular bonds that hold water molecules rigidly in place in ice crystals

Latent Heat

- Latent Heat of Vaporization
  - Amount of heat that must be added to a substance at its boiling point to break the intermolecular bonds and change state from liquid to vapor
  - 540 calories/gram
  - All hydrogen bonds must be broken

Latent Heat

- Latent Heat of Evaporation
  - Evaporation = conversion of liquid to gas below the boiling point
  - 585 calories/gram
  - Lower temperature of surface water not at boiling point means more hydrogen bonds to break

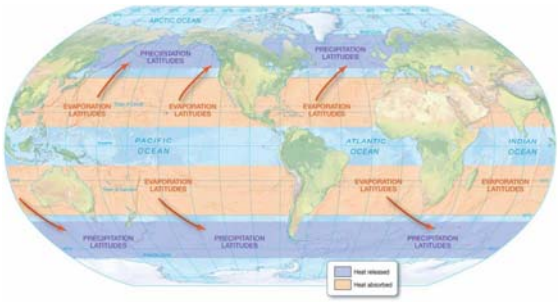
Latent Heat

- Latent Heat of Condensation
  - Cooled water vapor turns to liquid and releases heat to the environment
  - Identical to latent heat of vaporization
- Latent Heat of Freezing
  - Heat released when water freezes
  - Identical to latent heat of melting

Global Thermostatic Effects

- Water's properties moderate temperature on Earth's surface
  - Equatorial oceans do not boil
  - Polar oceans do not freeze solid
- Heat energy exchanged in evaporation-condensation cycle
  - Makes life possible on Earth

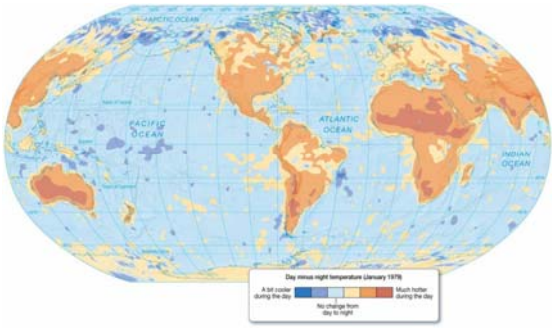
Atmospheric Heat Transport



Global Thermostatic Effects

- Marine effect
  - Oceans moderate temperature changes from day to night and during different seasons
- Continental effect
  - Land areas have greater range of temperatures from day to night and during different seasons

Day and Night Temperature Differences



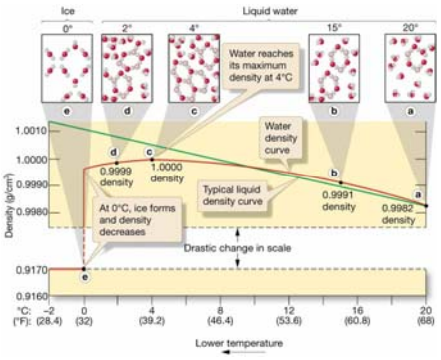
Water Density

- Density = mass/unit volume
- Density of water increases as temperature decreases.
  - Thermal contraction = shrinkage of most substances caused by cold temperatures

Water Density

- From 4°C to 0°C the density of water decreases as temperature decreases.
  - Unique property of water
- Ice is less dense than liquid water.
  - Changes in molecular packing
  - Water expands as it freezes.

Water Density and Temperature



Water Density

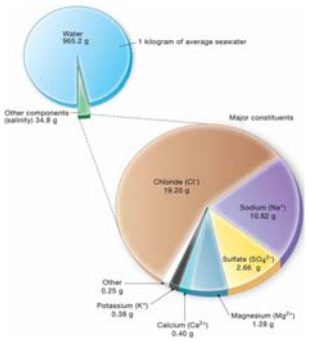
- Increasing pressure or adding dissolved substances decreases the maximum density temperature.
- Dissolved solids also reduce the freezing point of water.
  - Most seawater never freezes.

Salinity

- Total amount of dissolved solids in water including dissolved gases
  - Excludes dissolved organics
- Ratio of mass of dissolved substances to mass of water sample

Salinity

- Expressed in parts per thousand (ppt)
- Typical ocean salinity is 35 ppt ($^{o}/_{oo}$)



Seawater

TABLE 5.1 SELECTED DISSOLVED MATERIALS IN 35‰ SEAWATER

1. Major constituents (in parts per thousand by weight, ‰)

Constituent	Concentration (‰)	Ratio of constituent/total salts (%)
Chloride (Cl^-)	19.2	55.04
Sodium (Na^+)	10.6	30.61
Sulfate (SO_4^{2-})	2.7	7.68
Magnesium (Mg^{2+})	1.3	3.69
Calcium (Ca^{2+})	0.40	1.16
Potassium (K^+)	0.38	1.10
Total	34.58‰	99.28%

2. Minor constituents (in parts per million by weight, ppm[a])

Gases		Nutrients		Others	
Constituent	Concentration (ppm)	Constituent	Concentration (ppm)	Constituent	Concentration (ppm)
Carbon dioxide (CO_2)	90	Silicon (Si)	3.0	Bromide (Br^-)	65.0
Nitrogen (N_2)	14	Nitrogen (N)	0.5	Carbon (C)	28.0
Oxygen (O_2)	6	Phosphorus (P)	0.07	Strontium (Sr)	8.0
		Iron (Fe)	0.002	Boron (B)	4.6

3. Trace constituents (in parts per billion by weight, ppb[b])

Constituent	Concentration (ppb)	Constituent	Concentration (ppb)	Constituent	Concentration (ppb)
Lithium (Li)	185	Zinc (Zn)	10	Lead (Pb)	0.03
Rubidium (Rb)	120	Aluminum (Al)	2	Mercury (Hg)	0.03
Iodine (I)	60	Manganese (Mn)	2	Gold (Au)	0.005

[a]Note that 1000 ppm = 1‰.
[b]Note that 1000 ppb = 1 ppm.

Determining Salinity

- Evaporation
  - Early technique
  - Weigh water and weigh evaporated salts
  - Not accurate because some salts can evaporate with water

Determining Salinity

- Salinometer
  - Measures water's electrical conductivity
  - More dissolved substances increase conductivity

Determining Salinity

- Principle of Constant Proportions
  - Chemical analysis via titration
  - Major dissolved constituents in same proportion regardless of total salinity
  - Measure amount of halogens (Cl, Br, I, F) (chlorinity)
  - Salinity = 1.80655 * Chlorinity *(ppt)*

Pure Water vs. Seawater

TABLE 5.2 COMPARISON OF SELECTED PROPERTIES OF PURE WATER AND SEAWATER

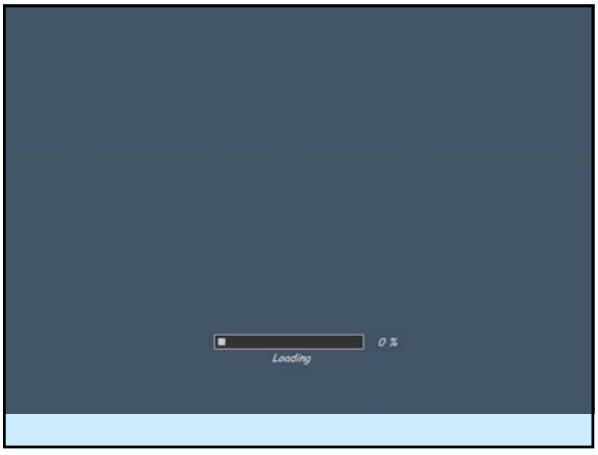
Property		Pure water	35‰ seawater
Color (light transmission)	Small quantities of water	Clear (high transparency)	Same as for pure water
	Large quantities of water	Blue-green because water molecules scatter blue and green wavelengths best	Same as for pure water
Odor		Odorless	Distinctly marine
Taste		Tasteless	Distinctly salty
pH		7.0 (neutral)	Surface waters, range = 8.0–8.3; average = 8.1 (slightly alkaline)
Density at 4°C (39°F)		1.000 g/cm^3	1.028 g/cm^3
Freezing point		0°C (32°F)	–1.9°C (28.6°F)
Boiling point		100°C (212°F)	100.6°C (213.1°F)

Salinity Variations

- Open-ocean salinity is 33–38 $^{o}/_{o}$.
- In coastal areas salinity varies more widely.

Salinity Variations

- Brackish
  - Influx of fresh water from rivers or rain lowers salinity
- Hypersaline
  - High evaporation conditions
  - Dead Sea
- Salinity may vary with seasons (dry/rain).



Processes Affecting Salinity

- Decreasing salinity – adding fresh water to ocean
  - Runoff, melting icebergs, melting sea ice
  - Precipitation
- Increasing salinity – removing water from ocean
  - Sea ice formation
  - Evaporation

Processes Affecting Salinity

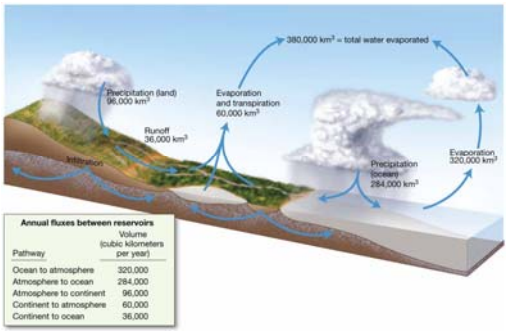
TABLE 5.3 PROCESSES THAT AFFECT SEAWATER SALINITY

Process	How accomplished	Adds or removes	Effect on salt in seawater	Effect on H_2O in seawater	Salinity increase or decrease?	Source of freshwater from the sea?
Precipitation	Rain, sleet, hail, or snow falls directly on the ocean	Adds very fresh water	None	More H_2O	Decrease	N/A
Runoff	Streams carry water to the ocean	Adds mostly fresh water	Negligible addition of salt	More H_2O	Decrease	N/A
Icebergs melting	Glacial ice calves into the ocean and melts	Adds very fresh water	None	More H_2O	Decrease	Yes, icebergs from the Antarctic have been towed to South America
Sea ice melting	Sea ice melts in the ocean	Adds mostly fresh water and some salt	Adds a small amount of salt	More H_2O	Decrease	Yes, sea ice can be melted and is better than drinking seawater
Sea ice forming	Seawater freezes in cold ocean areas	Removes mostly freshwater	30% of salts in seawater are retained in ice	Less H_2O	Increase	Yes, through multiple freezings, called freeze separation
Evaporation	Seawater evaporates in hot climates	Removes very pure water	None (essentially all salts are left behind)	Less H_2O	Increase	Yes, through evaporation of seawater and condensation of water vapor, called distillation

Earth's Hydrologic Cycle

- Processes that affect seawater salinity
- Recycles water among ocean, atmosphere, and continents
- Water in continual motion between water reservoirs

Earth's Hydrologic Cycle



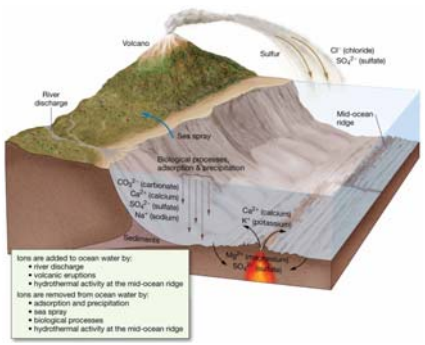
Earth's Water

- 97.2% in the world ocean
- 2.15% frozen in glaciers and ice caps
- 0.62% in groundwater and soil moisture
- 0.02% in streams and lakes
- 0.001% as water vapor in the atmosphere

Residence Time

- Average length of time a substance remains dissolved in seawater
- Ions with long residence time are in high concentration in seawater.
- Ions with short residence time are in low concentration in seawater.
- Steady state condition – average amounts of various elements remains constant

Processes that Add/Subtract Dissolved Substances



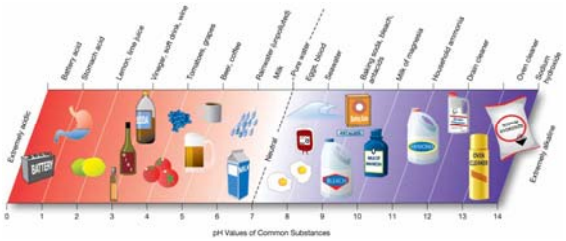
Acidity and Alkalinity

- Acid releases a hydrogen ion (H+) when dissolved in water.
- Alkaline (or base) releases a hydroxide ion (OH-) in water.

pH Scale

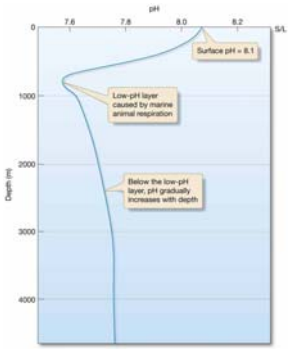
- Measures hydrogen ion concentration
  - pH value less than 7 = acid
  - pH value greater than 7 = base (alkaline)
  - pH 7 = neutral
    - Pure water

pH Scale



Ocean pH

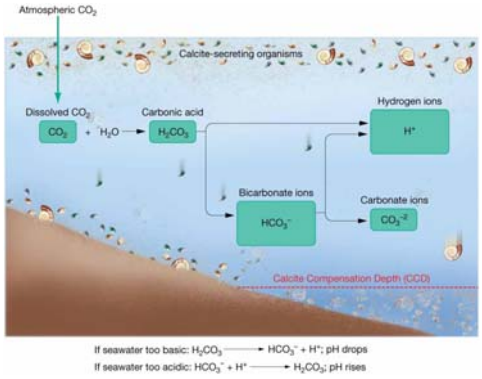
- Seawater is slightly alkaline
  - Surface water average pH 8.1
- Ocean water pH decreases with depth



Carbonate Buffering System

- Buffering keeps the ocean from becoming too acidic or too basic.
- Precipitation or dissolution of calcium carbonate, $CaCO_3$, buffers ocean pH.
- Oceans can absorb CO_2 from the atmosphere without much change in pH.

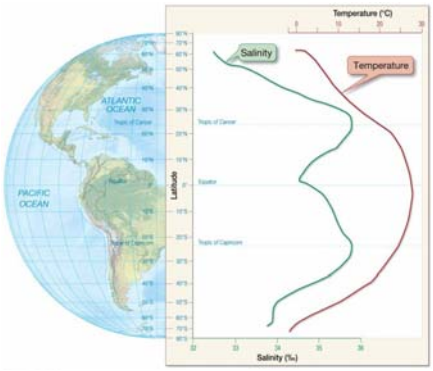
Carbonate Buffering System



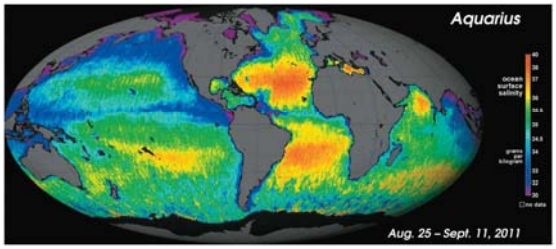
Surface Salinity Variation

- High latitudes
  - Low salinity
  - Abundant sea ice melting, precipitation, and runoff
- Low latitudes near equator
  - Low salinity
  - High precipitation and runoff
- Mid latitudes
  - High salinity
  - Warm, dry, descending air increases evaporation

Surface Salinity Variation by Latitude

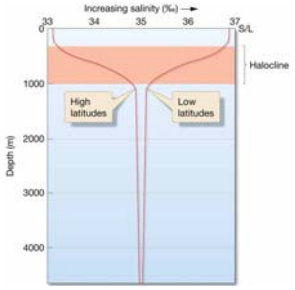


Aquarius Satellite View of Global Salinity, Aug.–Sept. 2011



Salinity Variation with Depth

- Low latitudes – salinity decreases with depth
- High latitudes – salinity increases with depth
- Deep ocean salinity fairly consistent globally
- Halocline – separates ocean layers of different salinity



Seawater Density

- Freshwater density = 1.000 g/cm^3
- Ocean surface water =1.022 to 1.030 g/cm^3
- Ocean layered according to density

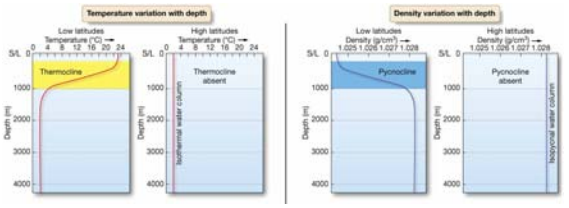
Seawater Density

- Density increases with decreasing temperature
  - Greatest influence on density
- Density increases with increasing salinity
- Density increases with increasing pressure
  - Does not affect surface waters

Temperature and Density Variations With Depth

- Pycnocline – abrupt change of density with depth
- Thermocline – abrupt change of temperature with depth

Temperature and Density Variations with Depth



Layered Ocean

Three distinct water masses based on density:

- Mixed surface layer – above thermocline
- Upper water – thermocline and pycnocline
- Deep water – below thermocline to ocean floor

Layered Ocean

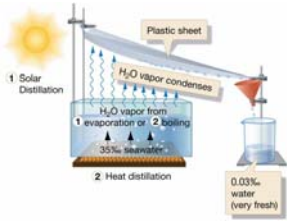
- High latitude oceans – thermocline and pycnocline rarely develop
  - Isothermal – no temperature variation in water column
  - Isopycnal – no density variation in water column

Desalinization

- Removing salt from seawater
- Human need for fresh water increasing, water supply decreasing
- Energy-intensive and expensive
- Most desalinization plants in arid regions
  - Provide less than 0.5% of human water needs

Desalinization

- Distillation
  - Most common process
  - Water boiled and condensed
  - Solar distillation in arid climates
- Electrolysis
  - Electrode-containing freshwater
  - Membrane between fresh and salt water tanks



Desalinization

- Reverse osmosis
  - Salt water forced through membrane into fresh water
- Freeze separation
  - Water frozen and thawed multiple times