**Chapter 6  
Water and Ocean Structure**

Some basic concepts:

**Compounds** - substances that contain two or more different elements in fixed proportions

**Element** - a substance composed of identical particles that cannot be chemically broken down into simpler substances

**Atoms** - the particles that make up elements

- A water molecule is composed of two hydrogen (H) atoms and one oxygen atom (O₂).
- A molecule is a group of atoms held together by chemical bonds.
- Water is a polar molecule, having a positive and a negative side.
- Chemical bonds, the energy relationships between atoms that hold them together, are formed when electrons - tiny negatively charged particles found toward the outside of an atom - are shared between atoms or moved from one atom to another.

- H₂O
  - Covalent bonds: shared pairs of electrons
  - Hydrogen bonds: bonds between water molecules due to polar structure

Hydrogen bonds form when the positive end of one water molecule bonds to the negative end of another water molecule.

Two important properties of water molecules:

**Cohesion** - the ability of water molecules to stick to each other, creating surface tension.

**Adhesion** - the tendency of water molecules to stick to other substances
Temperature, Heat, Heat Capacity, Calories, etc.

- **Temperature**
  - Measure of av. kinetic energy (motion) of molecules (KE=1/2mv²)
  - Unit is degrees C, F or K (Kelvin)

- **Heat**
  - Measure of the total kinetic energy of the molecules in a substance
  - Unit is the calorie

* Heat Capacity = is a measure of the heat required to raise the temperature of 1g of a substance by 1°C.

* Calorie = amount of heat to raise temperature of 1 gram of pure water by 1°C (from 14.5 °C to 15.5 °C)

* Latent Heat

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Not All Substances Have the Same Heat Capacity

<table>
<thead>
<tr>
<th>Substance</th>
<th>Heat capacity* (cal/g°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>0.06</td>
</tr>
<tr>
<td>Granite</td>
<td>0.20</td>
</tr>
<tr>
<td>Aluminium</td>
<td>0.22</td>
</tr>
<tr>
<td>Alcohol (ethyl)</td>
<td>0.30</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0.50</td>
</tr>
<tr>
<td>Acetone</td>
<td>0.81</td>
</tr>
<tr>
<td>Ice (not freezing or thawing)</td>
<td>0.51</td>
</tr>
<tr>
<td>Pure liquid water</td>
<td>1.00</td>
</tr>
<tr>
<td>Ammonia (gaz)</td>
<td>1.13</td>
</tr>
</tbody>
</table>

Water has a very high heat capacity, which means it resists changing temperature when heat is added or removed - large thermal inertia

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Remember from Chapter 3?

**Density** is a key concept for understanding the structure of Earth - differences in density lead to stratification (layers).

Density measures the mass per unit volume of a substance. 

\[
\text{Density} = \frac{\text{Mass}}{\text{Volume}}
\]

Density is expressed as grams per cubic centimeter.

- (pure) Water: has a density of 1 g/cm³
- Granite Rock: is about 2.7 times more dense

Temperature affects water's density - just about everything in this course!

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The relationship of density and temperature for pure water.

Note that points C and D both represent 0°C (32°F) but different densities and thus different states of water. Ice floats because the density of ice is lower than the density of liquid water.
States of matter

The three common states of matter — solid, liquid, and gas. On Earth, water can occur in all three states: gas, liquid, and solid.

- **A gas is a substance that can expand to fill any empty container.**

- **A liquid is a substance that flows freely in response to unbalanced forces but has a free upper surface in container it does not fill.** Liquids compress only slightly under pressure.
  - Gases and liquids are classed as **fluids** because both substances flow easily.
  - **A solid is a substance that resists changes of shape or volume.** A solid can typically withstand stresses without yielding permanently. A solid usually breaks suddenly.

Behavior of Water

- Governed by molecular processes
- Addition of heat: breaks H bonds first, then temperature rises
- Removal of heat: H bonds form, Energy releases as heat, prevents a rapid temperature drop
- Polarity (+/-): keeps molecules together

Water Becomes Less Dense When It Freezes

The space taken by 24 water molecules in the solid lattice could be occupied by 27 water molecules in liquid state, so water expands about 9% as the crystal forms.

Because molecules of liquid water are packed less efficiently, ice is less dense than liquid water and floats.

Changes of State due to addition or loss of heat (breaks H bonds)

The amount of energy required to break the bonds is termed the latent heat of vaporization. Water has the highest latent heat of vaporization of any known substance.
* melting/evaporation requires addition of heat: 80 and 540 calories, respectively.

For 1 gram of H₂O

* condensation/freezing release heat to the environment: 540 and 80 calories, respectively.

**Things to remember:**

1. Can have liquid water at 0°C and below (supercooled water)
2. Can change directly solid to gas - sublimation
3. Can boil water at temperature below 100°C (if pressure decreases as when at the top of a high mountain)
4. Evaporation removes heat from Earth’s surface (it is a cooling mechanism)
5. Condensation in atmosphere releases heat that will drive Earth’s weather cycle

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**Table 6-2, p. 161**

**Fig. 6-9, p. 163**

Add salt to pure water: the freezing point of seawater decreases with increasing density - this is seawater freezes at a lower temperature than pure water.
Adding salt to pure water → Seawater
96.5% of pure water and 3.5% dissolved material → Seawater

The effect of salt on water’s properties:

Dissolved salts in water
(a) raise T (temperature) of boiling point
(b) lower T of freezing point

(a) not so important to oceanography but (b) is, as T around 0°C are common over many areas of the oceans; freezing point of seawater ~ -2°C (-1.91 °C)

Heat Capacity
- The ability of a substance to take in or give up a certain amount of heat and undergo small or large changes in temperature
- Water has high heat capacity = 1 cal/g/°C
- Water can gain or lose large quantities of heat without large changes in temperature

- Salt does not significantly change water’s heat capacity; heat capacity of seawater = 0.96 cal/g/°C (4% change)

Cohesion and Surface Tension
- The holding together of water molecules by H bonds
- Surface tension: measure of how difficult it is to stretch or break the surface of a liquid
  - Addition of salt increases surface tension (this will effect wave formation)
  - Decreasing temperature increases surface tension
Density

- Density = mass per unit volume
- Measured in grams per cubic centimeters
  
  Density of pure water = 1 g/cm³
  
  (determined at ~ 4°C)
- Density **increases** as temperature **drops** to 4°C and then decreases as temperature goes to 0°C
- Ice is less dense than water
- Salt **increases** water's density
  
  Density of sea water > density of pure water
  
  ~ 1.03 g/cm³ at 4°C

Pressure

- Water nearly incompressible
- P increases by 14.7 lb/in² (1 Atmosphere) for every 10 m increase in depth of sea
- 1 cm³ will lose 1.7% of its volume at 4000 m
- Thus, sea level is 37 m lower due to compression!

I. Add salt to water and observe
1. Decrease freezing point (increase boiling point)
2. Not much change in heat capacity & latent heats
3. Increase surface tension (cohesion)
4. Increase (of course) in density

II. Increase temperature and observe
1. Decrease in seawater density (very sensitive to T)
2. Decrease in surface tension

III. But changes in pressure are mostly ignored by physical properties of water - seawater is nearly incompressible

Surface Water Moderates Global Temperature

San Francisco Norfolk

Temperature (°F)

San Francisco Norfolk

Temperature (°C)

San Francisco Norfolk
Ocean-Surface Conditions Depend on Latitude, Temperature, and Salinity

Table 6.2 Some Characteristics of the World Ocean Surface, by Latitude

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Tropical Oceanic Waters</th>
<th>Temperate Oceanic Waters</th>
<th>Polar Oceanic Waters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual variation of temperature</td>
<td>Less than 5°C (9°F)</td>
<td>About 10°C (50°F)</td>
<td>Less than 5°C (9°F)</td>
</tr>
<tr>
<td>Average salinity</td>
<td>35‰–37‰</td>
<td>About 35‰</td>
<td>28‰–32‰</td>
</tr>
<tr>
<td>Annual variation of air temperature</td>
<td>Less than 5°C (9°F)</td>
<td>About 10°C (50°F)</td>
<td>Up to 40°C (72°F)</td>
</tr>
<tr>
<td>Precipitation-evaporation balance</td>
<td>E exceeds P</td>
<td>P exceeds E</td>
<td>P exceeds E</td>
</tr>
</tbody>
</table>

Sea-surface temperatures during Northern Hemisphere summer

Sea-surface average salinities in parts per thousand (‰).

The Ocean Is Stratified by Density

Two samples of water can have the same density at different combinations of temperature and salinity.
The Ocean Is Stratified into Three Density Zones by Temperature and Salinity

- A. The surface zone or surface layer or mixed layer
- B. The pycnocline, or thermocline or halocline
- C. The deep ocean (~80% of the ocean is below the surface zone)

![Typical temperature profiles at polar, tropical, and middle (temperate) latitudes. Note that polar waters lack a thermocline.]

Sound and light in Seawater

- Sound and light both travel in waves
- Refraction is the bending of waves, which occurs when waves travel from one medium to another
- Refraction can bend the paths of light and sound through water
- Light may be absorbed, scattered, reflected, refracted and attenuated (decrease in intensity over distance)
- Sunlight does not travel well in the ocean. Scattering and absorption weaken light

Light

- Form of electromagnetic radiation
- Seawater transmits visible portion of the electromagnetic spectrum (water transmits blue light more efficiently than red)
- 60% is absorbed by 1 m depth
- 80% absorbed by 10 m depth
- No light penetration below 1000 m
- Shorter wavelengths (blues) are transmitted to deeper depths
Water Transmits Blue Light More Efficiently Than Red

most of the ocean lies in complete blackness

Sound Travels Much Farther Than Light in the Ocean

On average:
- Sound in Air = 334 m/s
- Sound in Water = 1500 m/s

Sound increases as temperature and pressure increase: sound travels faster in warm surface waters and then again in deep (cold) waters where pressures are higher

The so(fixing):a(and):r(ranging) zone

The so(fixing):a(and):r(ranging) zone is particularly efficient - that is, sounds can be heard for great distances - because refraction tends to keep sound waves within the layer.

The shadow zone
Sonar Systems Use Sound to Detect Underwater Objects

Pulses are sent from an array on a vessel, some energy reflects back from the surface of objects. The echo is analyzed to plot the position of the submarine.

Side-scan sonar: use a submerged array and tow it, send sound pulses that will bounce from bottom to receive by device, process images (computers).

Chapter 6 - Summary

Water is a polar chemical compound composed of two hydrogen atoms and one oxygen atom. Its remarkable thermal properties result from the large number and relatively great strength of hydrogen bonds between water molecules.

Heat and temperature are not the same thing. Heat is energy produced by the random vibration of atoms or molecules. Heat is a measure of how many molecules are vibrating and how rapidly they are vibrating.

Without water’s unique thermal properties, temperatures on Earth’s surface would change dramatically with only minor changes in atmospheric transparency or solar output. Water acts as a “global thermostat.”

Water density is greatly influenced by changes in temperature and salinity. Water masses are usually layered by density, with the densest (coldest and saltiest) water on or near the ocean floor. Differences in the density of water masses power deep ocean circulation.

Light and sound are affected by the physical properties of water, with refraction and absorption effects playing important roles.