Temperature, Salinity, and Density

The **density** of a substance is defined as its mass divided by its volume (usually expressed as grams per cubic centimeter, g/cm³), or in other words, how “heavy” it is for the space it occupies. The density of pure water is exactly 1.0000 g/cm³ at 4°C, but this number changes if the water temperature changes or if dissolved materials (like salts) are added. The density of seawater varies from about 1.020 g/cm³ and 1.030 g/cm³, so that a sample of seawater weighs between 2% and 3% more than an equal volume of pure water. This may seem like a small difference, but it has extremely important implications in determining how the ocean is layered (or stratified), and as a contributing factor in the forces that drive ocean circulation (*see Lab #6*).

Except for cold water within a few degrees a freezing (see “The Curious Behavior...” below), density increases as water temperature decreases. Thus cooler water tends to sink relative to warmer water (again, with the notable exception of water near freezing). As dissolved minerals (salts) are added to seawater, it also becomes more dense, so higher-salinity water will sink relative to lower-salinity (we often say “ fresher”) water. In general, then, throughout most of the ocean we find warmer, fresher water overlying colder, saltier water.

In terms of percent (which really means “parts per hundred”), the average salinity of the world ocean is 3.5%. Oceanographers, however, prefer to use a unit called *parts per thousand*, abbreviated ppt or ‰ or per mil. Converting percent to parts per thousand gives a value of 35‰ for average ocean salinity.

**Stratification and the “Clines”**

Two fluids having different densities will organize into layers, with the less dense fluid floating on top of the denser fluid (think of a bottle of oil and vinegar salad dressing). This layering is known as **stratification**. Even just one fluid, such as seawater, which may have density differences due to temperature and salinity, can form internal layers that are resistant to mixing. In the ocean, this stratification may be due entirely to temperature, entirely due to salinity, or (more commonly) the result of both temperature and salinity variations. As a general rule, the ocean is a “three-layer cake”. First, there is a relatively thin (usually a few tens to a few hundred meters), low-density upper layer that is either warm, low salinity, or both. Second, there is a transition layer in which the density characteristics change rapidly with depth. The third, or deepest layer,
which is by far the largest of the three layers, is also the densest layer, usually characterized by cold temperatures and high salinity.

The transition layer between the upper, low-density layer and the deep, high-density layer is known as the pycnocline (Figure 5-1). Since the density stratification may be due to temperature, salinity, or both, the pycnocline itself can be associated with a temperature transition layer known as a thermocline, a salinity transition layer known as a halocline, or a combination of the two (Figure 5-1).

![Diagram of ocean layers with pycnocline, thermocline, and halocline](image)

**Figure 5-1.** Density stratification in the ocean. [Source: Essentials of Oceanography, Tom Garrison. 4th / 5th editions. Thomson Brooks/Cole.]
The Curious Behavior of Water Density Near Freezing

Usually, when a liquid substance is cooled, its density increases, reaching a maximum when the liquid changes to solid form. Thus, a solid piece of most materials will sink when dropped into a liquid sample of that same material. One of water’s unique properties is that it follows that behavior only to a point, then does just the opposite if it is cooled further. As Figure 5-2 shows, the density of liquid water does increase as it is cooled, but only until the temperature reaches about 4°C (for pure water). If cooled beyond that point, the density of water decreases, and when the phase change to ice occurs, the density abruptly becomes even lower. The lower density of ice also implies expansion, which explains why a container filled with water may burst if it is frozen. The implications of water’s odd behavior are that in cold polar regions, very cold water near freezing, and sea ice itself, will float on water that is a few degrees warmer! If it wasn’t for the fact that icebergs float, the Titanic might have sailed the oceans for many decades.

Figure 5-2. The relationship between density and temperature for pure water. [Source: Essentials of Oceanography, Tom Garrison. 4th / 5th edition. Thomson Brooks/Cole.]
Geographic Salinity Variations

Although global ocean salinities are found to be mostly within a narrow range (approximately 32% to 37%), the subtle differences that do exist from place to place can have important implications related to ocean circulation, as well as biological productivity. One of the tasks in this lab will involve looking at global surface salinity maps and trying to understand why some of the observed geographic variations in salinity exist. Two of the most important controls of surface salinity are climate and proximity of freshwater (i.e., river) discharge.

In hot, dry climates, for example, where evaporation from the ocean surface exceeds rainfall, we often find relatively high surface salinity values, since evaporation removes water molecules but leaves the salt behind. On the other hand, in regions with plentiful rainfall, or in coastal areas close to major river outflows, the input of freshwater can dilute the dissolved minerals, resulting in relatively low salinity. Oceanographers, therefore, must often be cognizant of climate zones and continental geography in addition to oceanic processes in order to explain salinity variations in the oceans.

Salinity Measurement

It might seem that the easiest way to measure the salinity of a sample of seawater would be to simply boil it until the all of the water is gone, then weigh the crusty solids remaining. Unfortunately, this turns out to be an inaccurate method because once the salts are dissolved in water, they tend to retain some water molecules in their crystalline structure even after boiling and drying.

Salinity can be precisely measured using chemical methods, which are made easier by the principle of constant proportions (also known as Forchhammer’s principle), which states that the relative proportions of all of the dissolved materials that compose salinity remains constant throughout the ocean. Therefore, we only really need to measure the concentration of one constituent of salinity, and knowing its proportion, extrapolate that to the total. The most abundant single component of salinity in the ocean is the chloride ion, and its concentration, called chlorinity, can be measured using common laboratory techniques. The drawback of such chemical measurements are that they require that many water samples be collected, brought on board, and analyzed, either in a shipboard laboratory or a laboratory on land – in either case a labor-intensive and time-consuming process.

Most modern salinity measurements are made using an electronic device known as a salinometer, which determines salinity by measuring the electrical conductivity of the seawater. Salinometers are relatively inexpensive, and are very easy and quick to use. The instrument can simply be lowered over the side of a vessel, producing a continuous record of instantaneous salinity versus depth as it is lowered, without having to actually collect and bring seawater samples onboard.
In this lab, we’ll be measuring the salinity of several unknown seawater samples using a handy little device known as a **portable refractometer** (Figure 5-3). This instrument works on the principle that the refractive index of seawater (basically how much light bends as it passes through the water) changes depending on the salinity of the water. Although this is not the most precise way to measure salinity, it makes up for lack of precision with its convenience and ease of use.

*Figure 5-3. Using a portable refractometer.*
Online Oceanography 101  
Laboratory Exercise #5  
Temperature and Salinity

Questions to Answer

Part 1 – Temperature vs. Depth Profiles

The vertical temperature structure of the ocean typically breaks down into three layers. Warm water tends to be less dense and “floats” on the top of the ocean, where it is heated by the sun. Cold water is denser, and sinks to the ocean bottom. The transition between the warm and cold layers, in which the temperature changes rapidly within a narrow depth range, is called the **thermocline**. In this exercise, we will consider this 3-layer temperature structure from the surface down to 2,000 meters, and compare the structure at high (polar) latitudes, middle (temperate) latitudes, and low (tropical) latitudes.

1. Plot the temperature vs. depth data given in the table below on the blank graph that follows. Notice that the X (horizontal) axis represents temperature (in degrees Celsius), and the Y (vertical) axis represents the depth (in meters). Use different colors to draw each of the four profiles.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Low Lat.</th>
<th>Mid-Lat. Summer</th>
<th>Mid-Lat. Winter</th>
<th>High Lat.</th>
</tr>
</thead>
<tbody>
<tr>
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<td>28</td>
<td>18</td>
<td>10.2</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>27.5</td>
<td>17.7</td>
<td>10.2</td>
<td>0</td>
</tr>
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<td>125</td>
<td>13</td>
<td>17.1</td>
<td>10.2</td>
<td>1.5</td>
</tr>
<tr>
<td>250</td>
<td>7.2</td>
<td>10.1</td>
<td>10.1</td>
<td>3.5</td>
</tr>
<tr>
<td>375</td>
<td>6.5</td>
<td>10</td>
<td>10</td>
<td>3.5</td>
</tr>
<tr>
<td>500</td>
<td>5.8</td>
<td>8.7</td>
<td>8.7</td>
<td>3.25</td>
</tr>
<tr>
<td>625</td>
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<td>7.5</td>
<td>7.5</td>
<td>3</td>
</tr>
<tr>
<td>750</td>
<td>5</td>
<td>6.5</td>
<td>6.5</td>
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<tr>
<td>875</td>
<td>4.5</td>
<td>5.8</td>
<td>5.8</td>
<td>2.5</td>
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<td>5.1</td>
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<td>3.2</td>
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<td>3.1</td>
<td>3.1</td>
<td>2</td>
</tr>
<tr>
<td>1,625</td>
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<td>3</td>
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<td>1,750</td>
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<td>2.8</td>
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<td>2.6</td>
<td>2.6</td>
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<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>1.25</td>
</tr>
</tbody>
</table>
Approximately where (in what depth range) is the primary thermocline: (if there is no thermocline, write “none”). Remember that the thermocline is a transition zone for temperature, so it encompasses a depth range (like “100m to 200m”). It is not simply a single depth.

a) at low latitudes______________________________
b) at mid-latitudes in summer______________________________
c) at mid-latitudes in winter______________________________
d) at high latitudes______________________________
3. In the upper 250 m of the ocean, which of the four temperature profiles shows:
   a) the most rapid temperature decline_______________________________
   b) the least rapid temperature decline_______________________________

4. In the deep ocean below 750 m, which of the four temperature profiles shows:
   a) the most rapid temperature decline_______________________________
   b) the least rapid temperature decline_______________________________

5. Notice that the sample temperature profile from the high latitude polar region looks quite different from the rest of the profiles, especially in the fact that colder liquid water is found on top of warmer liquid water in the upper part of the profile. Explain how this temperature profile could exist. [Hint: Think about what happens to the density of liquid water near freezing.]

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**Part 2 – Geographic Distribution of Sea Surface Salinity**

The salinity of the surface water in the world’s oceans depends to a large degree on precipitation and evaporation. In regions with high rainfall the ocean surface water becomes diluted with fresh water and the salinity is reduced. In regions where solar radiation is strong and temperatures are high, evaporation from the sea surface may exceed precipitation. High evaporation has the effect of increasing salinity, since it removes fresh water and leaves behind the dissolved salts. In this exercise, we will examine the geographic distribution of salinity. The following questions are based on Figures 5-4, 5-5, and 5-6, which depict the average distribution of surface salinity in the Pacific, Atlantic, and Gulf of Mexico, respectively. The contour lines on these charts are *isohalines*, or lines of constant salinity, expressed in units of **parts per thousand** (abbreviated as **ppt** or %, or **per mil**).
6. On Figures 5-4 and 5-5:
   a) Use a red pencil to color in all regions of the oceans in which the average surface salinity is greater than or equal to 36 ppt.
   b) Use a blue pencil to color in all regions of the oceans in which the average surface salinity is less than or equal to 34 ppt.
   c) Based on your map work in Questions #6a and #6b, make a general statement describing the distribution of sea surface salinity as a function of latitude. Explain why this occurs.

7. Study the isohalines for the Gulf of Mexico (Figure 5-6), and describe where the lowest salinities are found. Suggest a reason why this pattern exists.

8. The Red Sea and the Mediterranean Sea (salinities not shown on the following maps) are places characterized by very high surface salinities (as high as 39-40 parts per thousand). List as many reasons as you can think of to explain these high salinities.
Figure 5-4. Pacific Ocean – Average Sea-Surface Salinities.
Figure 5-5. Atlantic Ocean – Average Sea-Surface Salinities.
Figure 5-6. Gulf of Mexico – Average Sea-Surface Salinities.

Part 3 – Seawater Salinity Analysis

9. **Problem:** The BCC oceanographic lab technician, Homer Simpson, misplaced the record book in which we keep the log of where our seawater samples came from. We have four unlabeled bottles, and all we know is they came from four different locations:

- **Lake Washington**
- **North Pacific Ocean, 1200 nautical miles west of Los Angeles**
- **Puget Sound, near Everett Harbor (Snohomish River outflow)**
- **Central Puget Sound**

But...we don’t know which bottle is which! Your job is to help us sort out our samples so we can label them correctly. This will require some oceanographic detective work.
Procedure: Fortunately, we have a photograph of the salinity of each of the samples, taken through a very handy little instrument known as a salinity refractometer. This instrument works on the principle that the refractive index of seawater (basically how much light is bent as it passes into or out of the water) depends on the salinity of the water. Our refractometer measures the salinity (right-hand scale; in parts per thousand, ‰) of water samples. (It also shows the density, in g/cc, on the left-hand scale, but we don’t need to know that information for our current assignment.)

Fill out the following table, using the refractometers and seawater samples (HYBRID CLASS) or the images below (ONLINE CLASS). Note: Be accurate with your readings!

**Sample A** - Salinity___________‰

Probable Source:

Your Reasoning:

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**Sample B** - Salinity___________‰

Probable Source:

Your Reasoning:

---

**Sample C** - Salinity___________‰

Probable Source:

Your Reasoning:

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**Sample D** - Salinity___________‰

Probable Source:

Your Reasoning:
Refractometer Readings for the ONLINE CLASS

(The HYBRID CLASS will use refractometers and seawater samples)

Sample A

Sample B

Sample C

Sample D