Sea Water Density Lab

Objectives

- Understand the relationship among temperature, salinity and density
- Use sigma-t ($\sigma_t$) to express density
- Investigate and understand the effect of salinity on density
- Investigate and understand the effect of temperature on density
- Investigate the formation of ice in a saline solution and its effect on density
- Understand the concept of buoyancy and utilize this principle to construct an object that “floats” between two density layers

Introduction

Sea water density (mass per unit volume) affects vertical circulation in the ocean. Small density differences caused by surface heating or cooling can produce strong vertical currents. Temperature, salinity and pressure (depth) play roles in determining the density of a sea water sample.

As temperature increases, density decreases. The increase in temperature causes an increase in molecular activity, which translates into greater space between molecules.

As salinity increases, density increases. Salinity is usually measured as the total dissolved salts in a standard sample. As more salt is dissolved per unit volume, density increases.

As pressure increases, density increases. The deepest waters in the ocean are usually the densest due to the weight of the overlying water.

Introduction

Density can be measured directly by
1. weighing a known volume of sea water, or
2. measuring electrical conductivity, or
3. using a hydrometer or
4. using a refractometer.

Density is typically expressed in grams per cubic centimeter (g/cm$^3$). Typical sea water density might be 1.0261 g/cm$^3$. Since the density of sea water is always be greater than 1.0000 (the density of fresh water), and usually ranges between 1.0300 and 1.0200, oceanographers use a unit called sigma-t ($\sigma_t$). It saves space and writing!

$$\sigma_t = (\text{Sea water density} - 1) \times 1000$$
TDS Diagrams

The relationship between temperature, salinity and density is shown on the TDS (Temperature-Density-Salinity) diagram in Figure 1. Density is shown on the y-axis and salinity is plotted on the x-axis. Temperature is shown as curved lines running diagonally across the center of the plot.

![TDS Diagram](image)

**Figure 1.** Temperature-Density-Salinity
Procedure 1: The Effect of Salinity on Sea Water Density

In this procedure you will mix a water sample with salinity of $10^\circ/\text{oo}$. Then you will measure its density using a hydrometer. You will also determine a theoretical density using Figure 1. Following this, you will use two water samples $20^\circ/\text{oo}$ and $35^\circ/\text{oo}$ provided in the lab.

**Note:** When you finish with the $35^\circ/\text{oo}$ sample, save it for the next procedure!

![Figure 2. Procedure for making $10^\circ/\text{oo}$ water](image)

1. Make 300 g of $10^\circ/\text{oo}$ salinity seawater by dissolving 3.00 g of NaCl into 297 g of water (that's 3 parts in 300, or 10 parts per thousand). Using the 200 g electronic balance, carefully weigh out 3.00 g of NaCl to the nearest hundredth (0.01) in a plastic weigh boat.

2. Using the 600 g electronic balance, tare a 400mL beaker. Add 297 g of deionized water (DI) by filling the beaker to approximately 250mL using the DI tap at the back sink and then squeezing DI out of the plastic bottle slowly until the balance reads exactly 297.0 g.

3. Add the 3.00 g of salt from the weigh boat and stir until the salt is completely dissolved.

4. Transfer 200 mL of the solution to a 250 mL graduate.

5. Using a hydrometer and a thermometer, measure the density and the temperature of the mixture and record them in Table 1. Be sure the hydrometer is floating freely. Add more water to the graduate if necessary.

6. From Figure 1, determine the theoretical density at the given temperature and salinity.

7. Repeat this procedure (steps 4 – 6), using $20^\circ/\text{oo}$ and $35^\circ/\text{oo}$ salinity water provided by the instructor.

**Note:** Save your graduate of $35^\circ/\text{oo}$ salinity water for the next procedure!
Table 1. Temperature, Measured and theoretical densities of three water samples

<table>
<thead>
<tr>
<th>Salinity</th>
<th>Temperature (°C)</th>
<th>Measured Density (g/cm³)</th>
<th>Theoretical Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 °/oo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 °/oo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35 °/oo</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In Table 1, are your measured densities different from the theoretical values? How can you explain these differences? (Hint: What are the possible sources of error?)

Procedure 2: The Effects of Temperature on Density

Temperatures in the open ocean range from 2°C in the polar seas up to 30°C in some of the warmer regions of the Red Sea. In coastal waters, winter-time temperatures can fall below 0°C; and summer temperatures may exceed 40°C in the shallow waters over tidal flat areas. Of all the properties controlling seawater density temperature is probably the most important because the range is so large.

In this procedure you will use 35 °/oo water from the last step of Procedure 1. First you will warm this water to 30°C. Then you will chill it, measuring the density along the way.

1. Using the 35 °/oo salinity water in the graduate from the previous exercise, add a bit more 35 °/oo until the graduate is as full as possible without overflowing when the hydrometer is in it. Take the graduate and a glass thermometer to the warm water bath at the side of the room.

2. Stir the water in the graduate constantly but gently (the thermometers are glass!) to insure uniform heating of the water in the graduate. Warm the graduate in the water bath provided until the temperature is 30°C. Take the graduate back to your table and measure the density with a hydrometer and record both the density and temperature in Table 2. Be sure to remove the hydrometer and thoroughly stir the water in the 250 mL graduate between density readings.

3. Fill a 2000 mL beaker about ¾ full of cold tap water.

   **Note:** Place the beaker on a clean dry cloth towel to prevent it from freezing to the table later in this exercise!

4. Place the 250 mL graduate containing 35 °/oo into the beaker. Stir the water in the graduate constantly with the thermometer except when you remove the thermometer and put in the hydrometer to measure the density. Record densities and temperatures in Table 2. Be sure to remove the hydrometer and thoroughly stir the water in the 250 mL graduate between density readings.
5. When your 35\(^{0}/\text{oo}\) water has reached a temp of 25\(^{0}\) add a little ice to the water bath to cool it down. Continue to measure temperatures and densities every 2\(^{0}\) or so. When your salt water reaches a temperature of about 15\(^{0}\), your instructor will add dry ice to continue lowering the temperature. Your instructor will dispense the dry ice as it is extremely cold.

**Do not touch the dry ice with your bare hands or hold the beaker containing the dry ice with your bare hands.**

6. Continue recording densities until the temperature reaches 5\(^{0}\). Reserve this chilled water in the graduate for the next exercise. The graduate will probably be frozen in place in the beaker. **Do not try to break it free!** Your instructor will assist you with transferring the contents of the graduate to the Erlenmeyer flask.

7. Plot the data in Figure 3.

### Table 2. Temperature and density of a 35\(^{0}/\text{oo}\) water sample

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Density (g/cm(^{3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Add ice here</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Add dry ice here</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Stop, Take Erlenmeyer flask to back of room to pack with dry ice (done for you). Go to Procedure 3

**NOTE:** The amount of time between readings is not as important as making sure that you have a density recorded for every drop in temperature of about 2 degrees.
Is the change in density with temperature a "linear" change over your experimental temperature range?________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________

Assume you were heating up a liter of 20º/oo water with a sunlamp. The temperature increases from 10ºC to 30 ºC. At the same time some of the water evaporated and the salinity went from 20 to 40º/oo. What is the initial and what is the final density? Which is the more important factor (temperature or salinity) affecting the density?
_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________

**Procedure 3: The Effect of Ice Formation on Density**
The densest water in the ocean is the Antarctic bottom water. The high density of this water is the result of low temperature and the formation of sea ice. As ice forms, fresh water is “frozen” out of the sea water, leaving behind very salty, very dense water. In this procedure you will use your chilled 35 º/oo water sample from the last exercise. This will be chilled in an Erlenmeyer flask until about one third of the water freezes.

1. Transfer the last temperature and density from the previous exercise (Table 2) to the appropriate blanks in Table 3 and find the corresponding salinity using Figure 1 and insert that number in Table 3.

2. Your teacher/lab assistant will pack the Erlenmeyer flask in the 2000 mL beaker with dry ice (Figure 4). Go back to your seat. Do not touch the sides of the beaker with your bare hands (use a towel)! The dry ice may freeze your skin to the beaker.
3. As the water in the flask cools, occasionally **stir very gently** using a glass stirring rod (not the thermometer). This is done to keep the water temperature homogeneous throughout the flask. **Do not disturb the ice as it forms. We want the ice to collect on the inside walls of the flask, not form slush in the flask.** Gently “feel” the inside wall of the flask with glass rod until you detect the formation of ice crystals. At this point, note the temperature of the first formation of ice. Use Figure Five below to determine the theoretical temperature at which you might **expect** ice to begin forming. Compare this to the actual measured temperature the ice forms in the space below.

measured temperature of ice formation:_________        theoretical temperature:___________

Why are the two temperatures of first ice formation (measured and theoretical) different? (hint: consider sources of error in the experimental results!)

4. Let the water/ice mixture continue to form until approximately one third of the salt water is ice. The remaining liquid that doesn't freeze is called "brine". When approximately half of the water in the flask is frozen (monitor the thickness of the ice on the inside wall of the flask using the glass stirring rod), pour approximately 200mL of the brine solution into a 250mL graduate. Measure the temperature with the thermometer and density with a hydrometer. Determine the salinity from Figure 1. Record the temperature, density and salinity in **Table 3**.

**Table 3.** Temperature, density and salinity of 35°/oo water before and after ice formation

<table>
<thead>
<tr>
<th>Sample</th>
<th>measured density</th>
<th>measured temperature</th>
<th>salinity (from Fig. One)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5°C 35°/oo water before ice formation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>brine after ice formation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

How does the salinity of the brine differ from the salinity of the original water sample? From this, what can you infer about the salinity of sea ice?

_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________
Procedure 4: Constructing a Swallow float

An aquarium has been set up to represent a model ocean with two water masses of different densities. These water masses have been dyed with food coloring to help show the boundary between the different density layers. Your job is to create a float that remains at the interface of the two water masses.

1. Samples from each of the water layers have been drawn and are in hydrometers next to the aquarium. The blue layer is denser cold salty water (bottom) and the yellow layer is lighter warm fresh water (top). Measure the density of each layer using the hydrometers provided. Record the densities below.

   surface (yellow) layer:___________  deep (blue) layer:__________

2. Weigh a 0.5 dram glass vial (plus cap) to the nearest 0.01 g using a 200 g balance.

   mass of the empty vial and cap:__________

Figure 5. Freezing point and maximum density as a function of salinity and temperature
3. Fill the vial about 1/3 full with lead shot and measure its volume to the nearest 0.1 cm³ by immersing the vial in fresh water in a 25 mL graduate. Read the volume of water in the graduate precisely before you add the vial. Tilt the graduate slightly and slide the vial into the graduate slowly so that you don’t splash any water out or trap any air bubbles! Then read the volume of water again. Subtract the first volume from the second to arrive at the volume of the vial. Remember Archimedes principle!

    volume of the vial:_____________mL

4. Calculate the density needed to just sink through the upper surface and float on the lower layer. In other words, calculate the density halfway between the upper and lower layers. This is easily done by adding the density of the upper and lower layers and dividing by 2.

    \[
    \frac{\text{density of blue layer} + \text{density of yellow layer}}{2} = \text{_____________} \text{g/cm}^3
    \]

5. We now know the volume of the vial and the density it should be. We need to find the mass. Recall that

    \[
    \text{density} = \text{mass} / \text{volume}
    \]

    so, by rearranging the equation

    \[
    \text{mass} = \text{density} \times \text{volume}
    \]

6. Calculate the desired mass of your float by multiplying the desired density (step 4 above) by the volume (step 3 above)

    Calculated mass of float:__________ g

7. Now we will adjust the mass of our vile to equal the calculated float mass. Place the empty vial and its cap on the balance and slowly add lead shot until the mass equals the calculated value.

8. Being careful not to disrupt the water layers, carefully place your float in the aquarium. If you made all of your measurements carefully and performed your calculations correctly, your float will settle at the interface of the two water layers. If your float sinks to the bottom or floats at the top, you will need to retrieve it with the tongs. Go back and check your work. Adjust the weight as indicated by your review of your work and try again!

Would it be possible to make a Swallow float for a fresh water lake? Explain your answer.

____________________________________________________________________________
____________________________________________________________________________