A SourceBook Module

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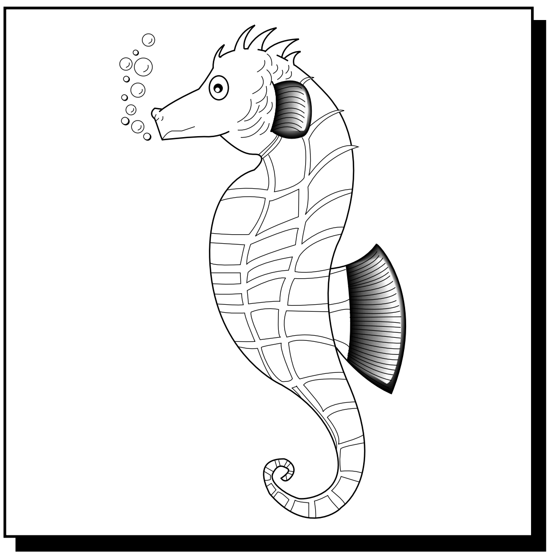
THE CHEMISTRY OF SEAWATER



ChemSource

Instructional Resources for Preservice and Inservice Chemistry Teachers

Topic Overview

Content in a Nutshell

Life on our planet would be impossible without water. Approximately three-quarters of the earth's surface is covered with water, nearly all of which (98%) is non-potable seawater. There are over fifty million billion (5×10^{12}) tons of sodium chloride and numerous other salts dissolved in the oceans. The chemistry of seawater is the chemistry of a huge solution and can be largely understood in terms of solution chemistry. Drawing on previously covered material, this module will demonstrate how concepts such as colligative properties, pH, density, and equilibrium can be applied to the sea.

In many respects (density, pH, and salinity) seawater is similar to human blood, lending credence to the idea held by most scientists that life evolved from the oceans.

Place in the Curriculum

This module, while it stands alone, could be used piecemeal to add to or replace portions of other modules. For instance, the freezing point and melting point activities could be done in the *Solutions* module, and the conductivity measurements described under demonstrations could be used when teaching the *Bonding* module to illustrate ionic substances. In turn, the *Solutions* module contains demonstrations of the Tyndall effect and the relationship between temperature and gas solubility that are suitable for inclusion in a discussion of seawater, and the *Biogeochemical Cycles* module details the carbon dioxide water equilibrium. This module is a natural extension of the module on *Alkali Metals*, since much of the chemistry of seawater revolves around the metal cations Na^+ and K^+.

Central Concepts

This is not a fundamental or core module so there are no concepts that absolutely "must be covered." Instead, the central theme of this module is that the chemistry of the oceans is the same as that covered in many other units, but applied to the complex system of the sea. The sea, in turn, is one component of the interaction between land, air, and sea. The questions to be asked and partially answered are:

1. What is seawater?
2. What are the physical and chemical properties of seawater?
3. Where do the components of seawater come from?
4. What are the uses of seawater?

Related Concepts

1. Acids/bases
2. Equilibrium, particularly LeChatelier's principle
3. Concentration units
4. Electrolytes and the conducting of electricity
5. Solubility
6. Thermochemistry
7. Colligative properties

RELATED SKILLS

1. pH calculations
2. Predictions of equilibrium shifts based on changing concentrations, pH, temperature, *etc*.
3. Unit conversions, particularly applied to concentrations (*e.g.*, molarity, ppm, g/L)

PERFORMANCE OBJECTIVES

After completing this module, students should be able to:

1. Define the components of seawater.
2. Describe and measure some of the important physical and chemical properties of seawater.
3. Discuss some of the important ramifications of the environment and seawater.
4. State some of the uses of seawater.

Concept/Skills Development

Laboratory Activity: Student Version

Note on Laboratory Activities

These two activities represent only a few examples of the types of experiments that can be used to demonstrate an investigative activity in chemistry. The major concepts of scientific measurement and data analysis, chemical reactions, stoichiometry, properties of solutions, acids and bases, oxidation-reduction reactions, and solubilities, to mention a few, are represented in these two activities.

Activity 1: Analysis of Seawater

Introduction

You will use the methods of chemical oceanography to conduct the water analysis in this investigation. Through these activities, you will solidify such concepts as the physical properties of water and pH. The investigation will be in the form of questions, and you are challenged to answer these questions using your knowledge of chemistry and the scientific method.

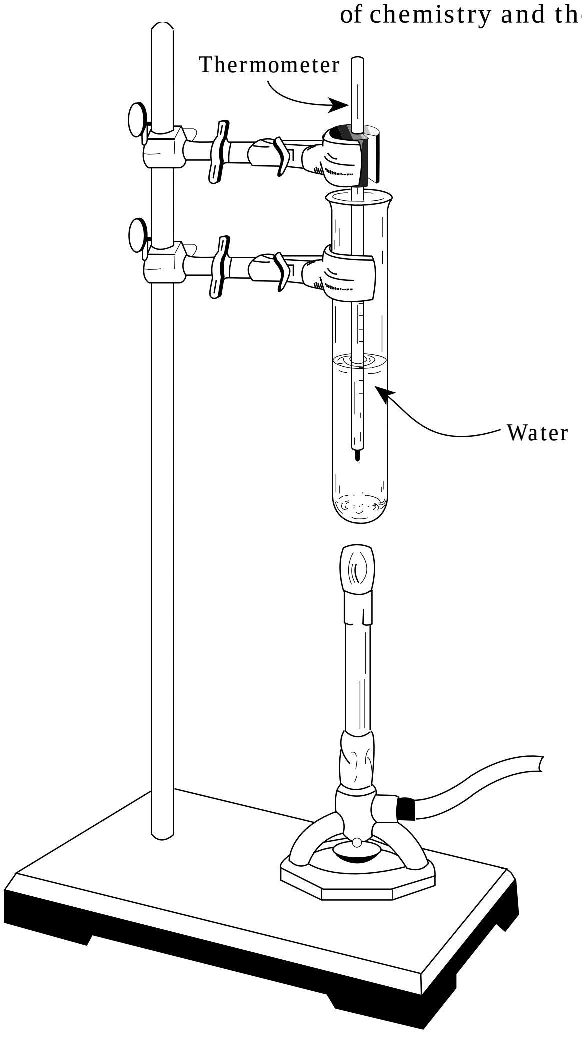


Figure 1. Boiling point apparatus.

Purpose

1. To investigate and compare some of the physical and chemical properties of seawater and distilled water.
2. To make predictions about the physical and chemical properties of seawater and distilled water (based on experiences in the high school chemistry course).
3. To test predictions.
4. To interpret data and draw conclusions based upon experimental results.

Safety

Wear protective goggles throughout the laboratory activity.

Part A. Boiling Point

The boiling point of a liquid is the temperature at which the vapor pressure of the liquid equals the opposing pressure of the atmosphere. The boiling point of water is commonly given as 100 °C at one atmosphere pressure.

Procedure

1. Set up the heating apparatus (Figure 1), measure and record the boiling point of distilled water. (Add boiling chips to prevent bumping.)
2. Record the barometric pressure. Repeat Step 1 with a seawater sample.
3. In a 100-mL beaker, evaporate 20 mL of seawater down to 15 mL. Determine the boiling point of this concentrated seawater using the set-up illustrated in Figure 1.
4. On a day with different weather, repeat Steps 1-3.
5. Thoroughly wash your hands before leaving the laboratory.

Data Analysis and Concept Development

Make a data table containing the boiling points of distilled water, seawater, and concentrated seawater at two different atmospheric pressures.

Implications and Applications

1. Are there any differences between the boiling points of the three substances measured?
2. How did a change in atmospheric pressure affect the boiling points?
3. Are seawater and fresh water affected in the same way by changing atmospheric pressure?
4. Why did increasing the concentration of salt (from Step 3) influence the boiling point?

Part B. Freezing Point

The temperature at which a substance becomes a solid upon cooling is its freezing point, which is identical to its melting point. For water, this temperature is assumed to be 0 °C. In this activity, we will measure the freezing point of water.

Procedure

1. Arrange a thermometer in the test-tube (Figure 2).
2. Cover the bulb of the thermometer with 15 mL water.
3. Pack the test-tube in some chunks of dry ice in a 600-mL beaker.
4. Record the temperature of the water every 30 sec (from the time the tube is just placed in the dry ice), until the temperature stabilizes.
5. Repeat Steps 1-4 using 15 mL seawater.
6. Take 20 mL seawater and evaporate to 15 mL. Measure its freezing point by repeating Steps 1-4.
7. Thoroughly wash your hands before leaving the laboratory.

Data Analysis and Concept Development

1. Make a data table of temperature *vs.* time for all three liquids.
2. Plot the data on a piece of graph paper with the temperature (°C) on the y-axis and the time (seconds) on the x-axis. Use different symbols for your data points for the three liquids (*e.g.*, x, 0 and D) or different colors to distinguish each curve.

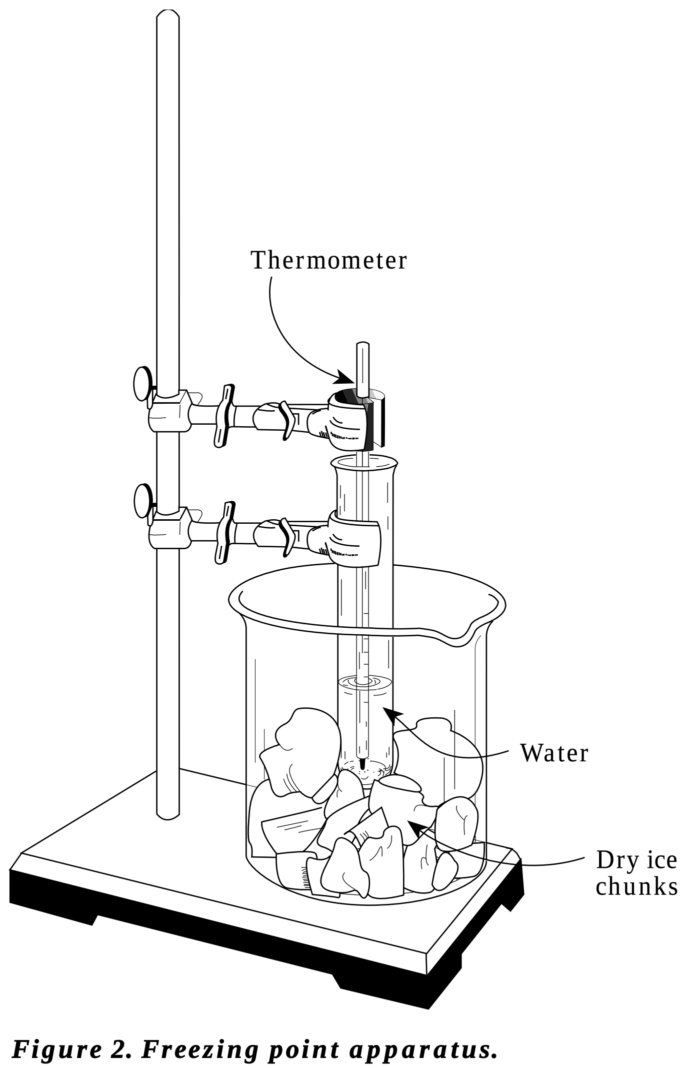


Figure 2. Freezing point apparatus.

Implications and Applications

1. Are there any differences in the freezing points of the three substances measured?
2. Is there any particularly unusual feature of this plot? What does it mean? What caused it?
3. How did increasing the concentration of salt (from Step 6) affect the freezing point of seawater?

Part C. pH of Seawater

The pH of a solution is a measure of its hydronium ion concentration $[H_3O^+]$. A reading of one on the pH scale represents a high H_3O^+ concentration and a very acidic solution. A very basic or alkaline solution, with low H_3O^+ concentration may read near 14 on the pH scale. A neutral solution will have a pH of 7 on the scale.

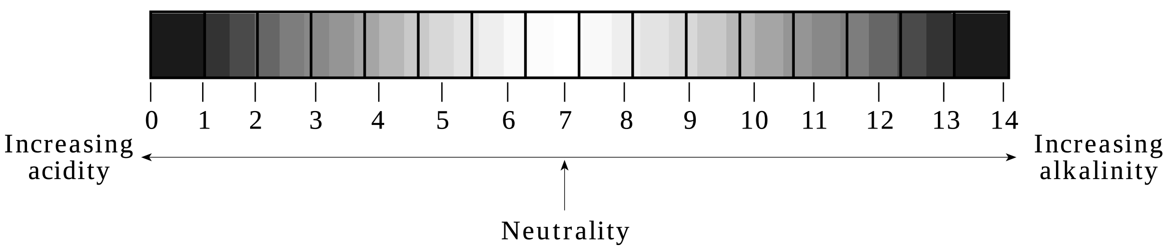


Figure 3. pH ranges.

pH 4.0	Red
pH 5.0	Orange-red
pH 5.5	Orange
pH 6.0	Yellow-orange
pH 6.5	Yellow
pH 7.0	Yellow-green
pH 7.5	Green
pH 8.0	Dark green
pH 8.5	Blue-green
pH 9.0	Blue
pH 9.5	Violet
pH 10.0	Reddish violet

Figure 4. Color chart for Fisher Universal Indicator.

Procedure

Testing distilled water and seawater with acid:

1. Place 50 mL distilled water into a 100-mL beaker. Add 25 drops universal indicator, stir, and record the pH by observing the color of the solution and comparing it with Figure 4.
2. Add one drop 0.1 M HCl, stir, and record the pH.
3. Repeat Step 2 until 20 drops have been added, noting the pH (color) after each drop.
4. Repeat Steps 1-3 using seawater.

Testing distilled water and seawater with base:

5. Repeat Steps 1-3, with distilled water and with seawater, but use 0.1 M NaOH instead of 0.1 M HCl
6. Thoroughly wash your hands before leaving the laboratory.

Data Analysis and Concept Development

1. Collect your data from Steps 1-5 using the following tables.

Drops 0.1 M HCl	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
pH Distilled water																					
pH Seawater																					

Drops 0.1 M NaOH	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
pH Distilled water																					
pH Seawater																					

Discussion

Most living organisms can tolerate only slight pH fluctuations near the neutral region of the pH scale. Under open ocean conditions, an effective pH “buffering” system limits seawater pH values to a narrow range between 7.5 and 8.4. This buffering system results from the interaction of dissolved carbon dioxide and water. Much of the carbon dioxide dissolved in seawater combines with water to produce a weak acid, carbonic acid. Normally, carbonic acid dissociates to produce hydrogen ions and bicarbonate or carbonate ions. These reactions can be summarized as shown below. For simplicity, we have represented H_3O^+ as H^+.

$$\underset{\text{Carbon dioxide}}{CO_2(g)} + \underset{\text{Water}}{H_2O(l)} \rightleftharpoons \underset{\text{Carbonic acid}}{H_2CO_3(aq)} \qquad (1)$$

$$\underset{\text{Carbonic acid}}{H_2CO_3(aq)} \rightleftharpoons \underset{\text{Hydrogen ion}}{H^+(aq)} + \underset{\text{Bicarbonate ion}}{HCO_3^-(aq)} \qquad (2)$$

$$\underset{\text{Bicarbonate ion}}{HCO_3^-(aq)} \rightleftharpoons \underset{\text{Hydrogen ion}}{H^+(aq)} + \underset{\text{Carbonate ion}}{CO_3^{2-}(aq)} \qquad (3)$$

If excess hydrogen ions are present, the reactions above proceed to the left. $[H^+]$ decreases, preventing the solution from becoming too acidic. If too few hydrogen ions are present, the reactions above proceed to the right, making more H^+ available and H_2CO_3 is converted to HCO_3^- and CO_3^{2-}.

Normally, the carbonate-bicarbonate buffering system limits large-scale fluctuations in seawater pH. Even so, in restricted water bodies such as tide pools and other areas of limited circulation, the pH of the water can vary enough to strongly affect the organisms living there.

Implications and Applications

1. Compare the buffering action of the distilled water *vs.* that of seawater.
2. Which liquid was the more effective buffer?
3. Can you think of other buffering systems in nature?

Laboratory Activity: Teacher Notes

Activity 1: Analysis of Seawater

Major Chemical Concept

Part A

The boiling points of distilled water and salt solutions depend on the concentration of solutes and the atmospheric pressure. The greater the ionic concentration, the greater the boiling point (at constant pressure), a result of the vapor pressure lowering caused by the presence of ions in the solution. The change in boiling point can be represented by the equation

$$\Delta T_b = K_b m_{solute}$$

where, ΔT_b is the difference between the boiling point of the solution and that of the pure solvent, K_b is a constant that is characteristic of the solvent and is called the **molal boiling point elevation constant**, and m_{solute} is the *molality* of the solute in the solution.

Part B

The freezing points of distilled water and salt solutions depend on the concentration of solute in the solution. The greater the ionic concentration, the lower the freezing point (at constant pressure), a result of vapor pressure lowering caused by the presence of ions in the solution. The change in freezing point can be represented by the equation

$$\Delta T_f = K_f m_{solute}$$

where, ΔT_f is the difference between freezing point of the solution and that of the pure solvent, K_f is a constant that is characteristic of the solvent and is called the **molal freezing point depression constant**, and m_{solute} is the *molality* of the solute in the solution.

Part C

Seawater has a buffering effect. It resists changes in pH, in contrast to distilled water.

Level

General high school chemistry.

Expected Student Background

Part A

The student should know the use and care of a thermometer and burner.

Part B

The student should know the use and care of a thermometer.

Part C

The student should know how to safely handle acid and base solutions.

Time

Part A

Students should be able to complete *Part A* in one 55-min period if they immediately begin the evaporation of the seawater for Step 3. Step 4 requires an additional 55-min period.

Part B

Students should be able to complete *Part B* in one 55-min period if they immediately begin the evaporation of the seawater for Step 5.

Part C

Students should be able to complete *Part C* in one 55-min period.

NOTE: The teacher can assign one third of the class to do Part A, *one third to do* Part B *and one third to do* Part C. *Students can then share the data on an overhead projector, allowing completion of the laboratory in one day, if desired.*

The teacher can prepare data for Part A, Step 4 *and the concentrated seawater ahead of time to shorten the laboratory time required.*

Safety

Read the *Safety Considerations* in the *Student Version*.

Materials (For 24 students working in pairs)

Part A

Nonconsumables

- 12 Burners and stands
- 12 Thermometers, –10 °C to 110 °C
- 12 Beakers, 100-mL
- 12 Test-tubes, 20- x 150-mm
- Barometer (or call the local weather bureau)

Consumables

- Boiling chips
- Distilled water
- Artificially prepared seawater (chlorinity–19.05 parts per thousand, ppt):
  - *Add to 1 L of distilled water:*
  - 27.53 g Sodium chloride (NaCl)
  - 5.79 g Magnesium chloride hexahydrate ($MgCl_2 \cdot 6H_2O$)
  - 14.17 g Magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$)
  - 1.82 g Calcium chloride dihydrate ($CaCl_2 \cdot 2H_2O$)
  - 1.23 g Potassium chloride (KCl)
  - 0.27 g Sodium hydrogen carbonate ($NaHCO_3$)

Part B

Nonconsumables

- 12 Ring stands
- 12 Thermometers, –10 °C to 110 °C
- 12 Beakers, 100-mL and 400-mL
- 12 Test-tubes, 20- x 150-mm

Consumables

- Graph paper
- Distilled water
- Seawater (see *Part A* for directions)
- Dry ice (solid CO_2), 6 lb

Part C

Nonconsumables

12 Beakers, 100-mL
12 Dropping bottles, Fisher universal indicator, pH range 4-10
12 Magnetic stirrers (optional)
24 Medicine droppers, or equivalent

Consumables

0.1 M Hydrochloric acid, HCl (4.2 mL 12 M HCl to 500 mL solution)
0.1 M Sodium hydroxide, NaOH (2.0 g NaOH to 500 mL solution)

Advance Preparation

Parts A and B

Prepare:

Artificial seawater or obtain seawater
Concentrated seawater (optional)

Part C

In addition to *Part A and B*, prepare:

0.1 M HCl
0.1 M NaOH

Pre-Laboratory Discussion

1. Students should be instructed to start the evaporation of the salt solution to make the concentrated salt solution first (if it is not being provided by the teacher).
2. Review the concepts of pH, buffers and colligative properties.
3. Discuss supercooling and how it might appear on a cooling curve.
4. Review proper graphing technique including title, axes labels, proper sizing of units on each axis.
5. Warn the students not to use the thermometer as a stirring rod because the fragile bulb at the end of the thermometer could break.
6. For *Part C*, if you have buffer solutions from pH 4 through pH 10, it would be helpful if students could see the actual universal indicator colors shown in Figure 4.

Teacher-Student Interaction

Circulate in the laboratory. Ask questions regarding expected results.

Post-Laboratory Discussion

1. Have the students place their freezing point and boiling point results on the board or overhead projector and determine the average class values.
2. Discuss why there is a range of values (difference in equipment, rate of heating, and rate of cooling).
3. Discuss the shapes of the cooling curves from *Part B*.
4. Discuss other natural buffering systems, like blood.

Anticipated Student Results

Part A

	Boiling point, °C
Distilled water	100.0 ± 0.5
Seawater	102.5 ± 0.5
Conc. seawater	103.0 ± 0.5

Figure 5. Student data table. Boiling points at pressure of 757 mm Hg.

Part B

Temperature °C	Time seconds
24	0
17	30
14	60
10	90
9	120
8	180
5	210
4	240
3	270
2.5	300
2	330
–3	360
1	390
0	420
0	450
0	480

Figure 6. Temperature vs. time for distilled water.

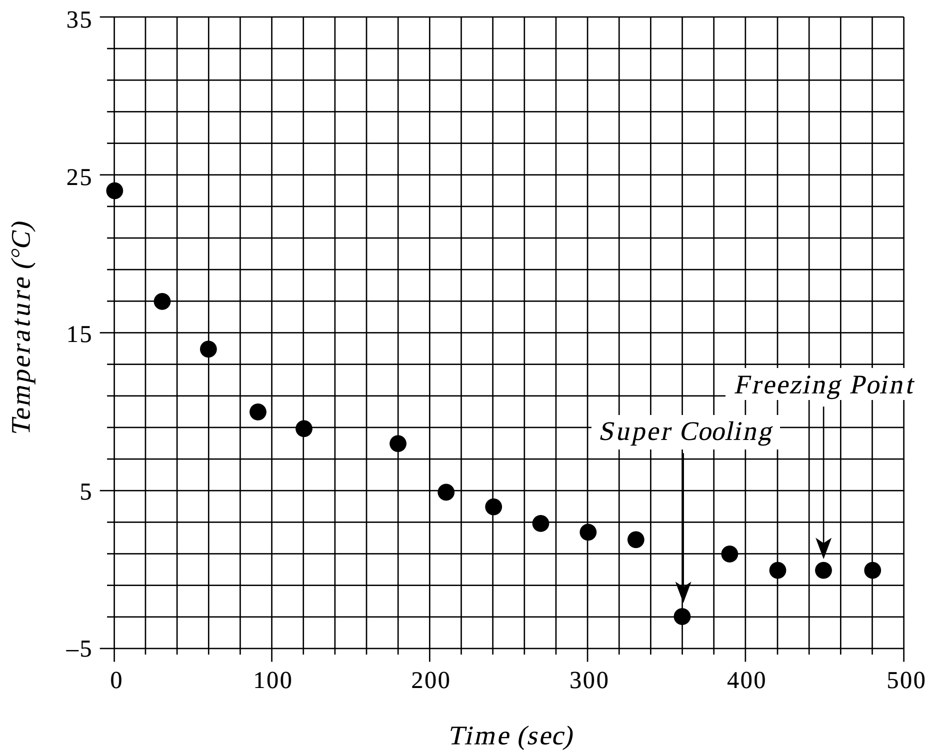


Figure 7. Freezing point curve for distilled water.

Temperature °C	Time seconds
23	0
16	30
12	60
5.5	90
2	120
1	150
–0.5	180
–1.5	210
–2	240
–2.5	270
–3	300
–3.5	330
–4	360
–5	420
–6	450
–6.5	480
–7	510
–8	540
–8	570
–8	600

Figure 8. Temperature vs. time for seawater.

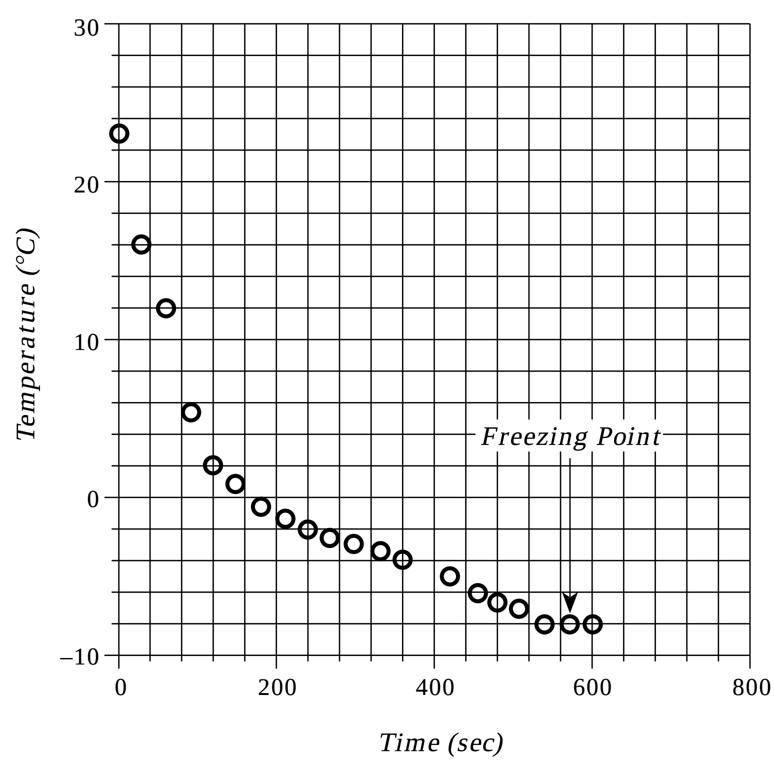


Figure 9. Freezing point curve for seawater.

Temperature °C	Time seconds
28.5	0
16	30
10	60
8	90
5.5	120
3.5	150
0	180
–5	210
–7	240
–8.5	270
–9	300
–9	330
–9	360

Figure 10. Temperature vs. time for concentrated seawater.

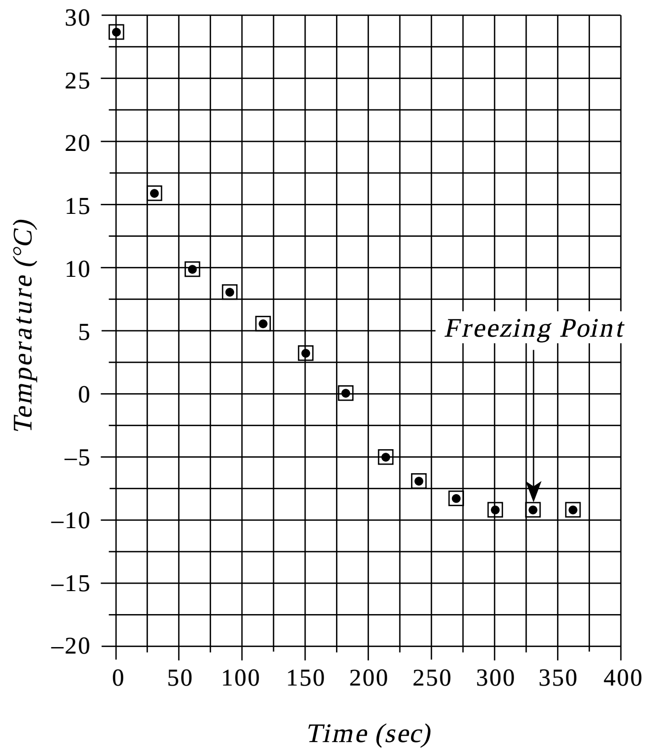


Figure 11. Freezing point curve for concentrated seawater.

Salinity (ppt)	Freezing point (°C)
0	0
10	–0.53
20	–1.08
30	–1.63
35	–1.91

Figure 12. Freezing point of seawater as a function of salinity.

Using the data from Figure 12 and their experimental freezing points, students can infer the concentrations of dissolved salts in their distilled water, seawater and concentrated seawater in parts per thousand.

Part C

Drops of 0.1 M HCl	pH Distilled water	pH Seawater
0	7.5	7.5
1	6.5	7.0
2	5.0	7.0
3	4.0	7.0
4	<4.0	7.0
5	<4.0	7.0
6	<4.0	7.0
7	<4.0	7.0
8	<4.0	6.5
9	<4.0	6.5
10	<4.0	6.5
11	<4.0	6.5
12	<4.0	6.5
13	<4.0	6.5
14	<4.0	6.5
15	<4.0	6.5

Figure 13. pH values of distilled water and seawater on addition of 0.1 M HCl.

Drops of 0.1 M NaOH	pH Distilled water	pH Seawater
0	7.5	7.5
1	9.0	8.0
2	9.5	8.5
3	10.0	8.5
4	>10.0	8.5
5	>10.0	8.5
6	>10.0	8.5
7	>10.0	8.5
8	>10.0	8.5
9	>10.0	8.5
10	>10.0	9.0
11	>10.0	9.0
12	>10.0	9.0
13	>10.0	9.0
14	>10.0	9.0
15	>10.0	9.0

Figure 14. pH values of distilled and seawater on addition of 0.1 M NaOH.

Answers to Implications and Applications

Part A

1. The boiling point of seawater increases as the salt concentration increases:

   Conc. seawater > Seawater > Distilled water

2. The boiling points increase slightly as the pressure increases.
3. Yes.
4. Increasing the salt concentration increases the boiling point, by molal boiling point elevation, a colligative property (see *Solutions* module).

Part B

1. Yes. Distilled water > Seawater > Conc. seawater.
2. The temperature stabilizes as soon as ice starts to form in the test-tube.
3. The freezing point decreases as the salt concentration increases, by molal freezing point depression, a colligative property (see *Solutions* module).

Part C

1. The pH changes rapidly with the addition of HCl or NaOH to distilled water. Addition of even large quantities of HCl or NaOH to seawater changes the pH only slightly.
2. Seawater.
3. One example is the buffering of blood by a CO_2/HCO_3^-. (There are also other buffers in the blood.)

Post-Laboratory Discussion

A discussion of supercooling will probably be in order after the students have plotted their results for *Part B*.

The teacher may wish to discuss the importance of the buffering effect of the HCO_3^-/CO_3^{2-} in the oceans and the environment.

Assessing Laboratory Learning

1. What is a buffer solution? *[A solution that resists changes in its pH when either an acid or a base is added.]*
2. Give an example of buffer solutions that occur in nature. *[Blood and seawater (any solution that resists changes in pH).]*
3. As the concentration of a salt in a solution is increased, what happens to the freezing point. Explain. *[The freezing point decreases. The depression is due to the colligative properties of the system (the solution has a lower vapor pressure than that of pure water).]*
4. As the concentration of a salt in a solution is increased what happens to the boiling point. Explain. *[The boiling point increases. The elevation is due to the colligative properties of the system (a nonvolatile solute elevates the boiling point of the solution because the vapor pressure of the liquid is decreased).]*
5. If a nonvolatile soluble substance were added to a liquid other than water, predict how its boiling point and freezing point be affected. Why? *[The boiling point would be elevated and the melting point would be depressed, but not to the same degree as water since the K_f and K_b values are different for each solvent.]*

LABORATORY ACTIVITY: STUDENT VERSION

Activity 2: Determination of the Salinity of Seawater

Introduction

This method involves chemical volumetric analysis. A silver nitrate ($AgNO_3$) solution of known concentration is used to precipitate out the chlorides in a seawater sample. The procedure is complicated by the fact that the dense white precipitate, silver chloride (AgCl), does not settle rapidly. It is impossible to tell when all the chlorides have been removed from the seawater unless an indicator is used to signal complete precipitation by a visual color change. The indicator in the analysis is chromate ion. When all of the chloride ion is exhausted, the chromate ion reacts with silver ions and produces silver chromate, which is red. The instant a permanent orange tinge appears in the solution (one that doesn't vanish with mixing), the addition of silver nitrate is stopped. The final solution color should look like that of orange juice.

The chemical reactions are:

$$Cl^{-}(aq) + Ag^{+}(aq) \rightarrow \underset{\text{(white)}}{AgCl(s)} \qquad (1)$$

$$2Ag^{+}(aq) + CrO_4^{2-}(aq) \rightarrow \underset{\text{(red-brown)}}{Ag_2CrO_4(s)} \qquad (2)$$

The titration is carried out in a 150-mL Erlenmeyer flask, using a white background and good lighting, but away from direct sunlight. Constant but gentle stirring is essential, since the silver chloride tends to form clots, which trap some of the reagents. A magnetic stirrer is very helpful. The silver nitrate is added until the faint reddish or orange tinge remains after stirring for 45 s. At this point one drop should give the desired end point. Observable flocs of silver chloride will obscure the end point, since the solutions that they contain in their interstices will leak out slowly and cause the end point to be impermanent. A stirring rod left permanently in the flask, especially if a magnetic stirrer is not used, will help to break up these curds.

Purpose

1. To determine the chlorinity (and thus the salinity, since they are directly related) of a sample of seawater.
2. To use the titration technique with a reaction different from an acid/base reaction.

Safety

Wear protective goggles throughout the laboratory activity. Avoid getting $AgNO_3$ on hands since it stains the skin.

Procedure

1. With a pipet deliver 5.0 mL seawater into a 150-mL Erlenmeyer flask.
2. Using a 10-mL graduated cylinder, add 5.0 mL potassium chromate indicator solution, and begin to add the silver nitrate solution from a buret while constantly stirring.
3. When the solution turns orange, stop adding silver nitrate. The color should persist for less than 20 sec. Continue adding silver nitrate dropwise, mixing all the while, until orange color persists. Record the volume of silver nitrate added.
4. Thoroughly wash your hands before leaving the laboratory.

Data Analysis and Concept Development

From a simple algebraic proportion one can determine the chlorinity of the seawater because it has been shown experimentally that the salinity is a constant 1.80655 times higher than the chloride level. Thus, the salinity (S) can be calculated (using the equation S ppt = 1.80655 Cl ppt; the chlorinity (Cl) of the artificial seawater should be about 19.05 ppt).

1. What is the number of moles of silver used in the titration ($AgNO_3$ is 0.2184 M)?
2. Determine the number of moles of chloride in the sample.
3. Determine the grams of chloride present in the sample.
4. What is the chlorinity of 10 g of sample? (The density of seawater is about 1.05 g mL^{-1}).
5. What is the salinity of the sample in ppt?

Laboratory Activity: Teacher Notes

Activity 2: Determination of the Salinity of Seawater

Major Chemical Concept

Quantitative determination of the chloride concentration in a sample of seawater.

Level

General high school chemistry

Expected Student Background

Students should have done titrations and titration calculations.

Time

55 min

Safety

Read the *Safety Considerations* in the *Student Version*.

Materials (For 24 students working in pairs)

Nonconsumables

- 12 Burets
- 12 Buret stands and clamps
- 12 Graduated cylinders, 10-mL
- 12 Erlenmeyer flasks, 150-mL
- 12 Magnetic stirrers (optional)
- 12 Pipets, transfer, 10-mL
- 2 Storage bottles, 1-L
- 1 Volumetric flask, 1-L

Consumables

- Distilled water (in wash bottle)
- Indicator solution (3.5 g, potassium chromate, K_2CrO_4, reagent grade, per liter solution)
- 0.2184 M Silver nitrate, $AgNO_3$ (37.11 g $AgNO_3$, reagent grade, to 1.000 L in a 1-L volumetric flask. Store solution in a tightly capped brown glass bottle.)

Advance Preparation

Prepare:

Potassium chromate (observe safety precautions)
Silver nitrate (observe safety precautions)

Pre-Laboratory Discussion

1. Demonstrate the proper titration techniques and remind students that silver nitrate will stain their hands.
2. Discuss the reaction that gives the red-brown color

   a. $$Cl^-(aq) + Ag^+(aq) \rightarrow \underset{\text{white}}{AgCl(s)}$$

   b. $$2Ag^+(aq) + CrO_4^{2-}(aq) \rightarrow \underset{\text{red-brown}}{Ag_2CrO_4(s)}$$

   and demonstrate a titration showing the students the final end point color.
3. Review the proper use of a transfer pipet.

Teacher-Student Interaction

Circulate in the laboratory. Ask questions comparing this titration with previously done acid-base titrations. Ask why it is not important to use an exact amount of indicator solution.

Post-Laboratory Discussion

Part A

Discuss differential solubility. Since the $Ag_2CrO_4(s)$ is much more soluble than AgCl(s), it is only after almost all of the AgCl(s) is precipitated that the red-brown end point be reached with the precipitation of $Ag_2CrO_4(s)$.

Anticipated Student Results

Trial	Volume of $AgNO_3$	Concentration of $AgNO_3$
1	28.05 ml	0.2184 M

Answers to Data Analysis and Concept Development

1. $(0.2184\ M\ AgNO_3)(0.02805\ L) = 0.006126\ mol\ AgNO_3 = 0.006126\ mol\ Ag^+$
2. $mol\ AgNO_3 = mol\ Cl^- = 0.006126\ mol$
3. $(mol\ Cl^-)\left(\frac{35.45\ g\ Cl^-}{1\ mol\ Cl^-}\right) = 0.2172\ g\ of\ Cl^-$
4. $\left(\frac{mass\ Cl^-}{mass\ 10\ mL\ seawater}\right)(1000) = Chlorinity\ (ppt)$

   $\left(\frac{0.217\ g\ Cl^-}{10.5\ g\ seawater}\right)(1000) = 20.7\ ppt$
5. $(1.80655)\ chlorinity(ppt) = Salinity\ (ppt)$

   $(1.80655)(20.7\ ppt) = 37.4\ ppt$

Post-Laboratory Discussion

Discuss solubility. Since the $Ag_2CrO_4(s)$ is much more soluble than AgCl(s), it is only after almost all of the AgCl(s) is precipitated that the red-brown end point is reached with the precipitation of $Ag_2CrO_4(s)$.

Assessing Laboratory Learning

1. If 24.0 mL of 0.250 M $AgNO_3$ is required to reach the end point of the seawater solution ($CrO_4^{2-}(aq)$ reaction with $Ag^+(aq)$ to give a red-brown precipitate), determine the number of moles of Cl^- ions present.

   [mol of $AgNO_3$ = (volume of $AgNO_3$) (molarity of $AgNO_3$)
   mol of $AgNO_3$ = (0.0240 L) (0.250 M) = 0.00600 mol of $AgNO_3$
   mol of $AgNO_3$ = mol of Cl^- = 0.00600 mol Cl^-]

2. Determine the grams of chloride present in the sample.

   $[(0.00600\ mol\ of\ Cl^-)\frac{35.45\ g\ Cl^-}{1\ mol\ Cl^-} = 0.213\ g\ of\ Cl^-]$

3. What is the chlorinity of a 10.0 mL sample? (The density of the seawater is determined to be 1.05 g/mL.)

$$[\frac{\text{Mass of } Cl^-}{\text{Mass of 10.0 mL of seawater}}(1000) = \text{Chlorinity (ppt)}$$

$$\frac{0.213 \text{ g } Cl^-}{(1.05 \text{ g/mL})(10.0 \text{ mL})}(1000) = 20.3 \text{ ppt}]$$

4. What is the salinity of the sample? (1.80655) Chlorinity (ppt) = Salinity (ppt)

[(1.80655) Chlorinity (ppt) = Salinity (ppt)
(1.80655) (20.3 ppt) = 36.7 ppt]

CAUTION: Use appropriate safety guidelines in performing demonstrations.

DEMONSTRATIONS

Demonstration 1: Comparison of the Electrical Conductivity of Distilled Water with Tap Water and Seawater

Purpose

The electrical conductivity of distilled (or deionized) water is compared with tap water and seawater as one indication of the amount of salt present. (The *Bonding* module describes the pertinent apparatus.)

Materials

9-volt Battery conductivity apparatus
Distilled water
Seawater

Safety

Use normal safety precautions.

Procedure

Test electrical conductivity of distilled water and seawater with the apparatus.

Extensions

Discuss why it is inadvisable to go swimming during a lightning storm.

Demonstration 2: Buoyancy and Density

Purpose

Part A simply demonstrates what buoyancy is and how we recognize it. *Part B* shows the relationship between density and buoyancy.

Materials

Part A

Beaker, 2-L or larger (or clear plastic pail)
Ice
Water, 2 L
Canned soft drinks, sweetened and sugar-free

Part B

2 Graduated cylinders, 1-L
Water (tap water or deionized water), 2 L
400 g Sodium chloride, NaCl, saturated solution, per L solution
2 Eggs (raw)

Safety

Use normal safety precautions.

Procedure

Part A

Fill a very large (2 L or larger) beaker or clear plastic pail with water and a little ice. Drop in one can of Pepsi and one can of Diet Pepsi (or Coke and Diet Coke). The sugared solution will sink to the bottom while the artificially sweetened solution, which is much less dense, will float at or near the top of the container.

Part B

Fill one graduated cylinder with tap water or deionized water; in the other place 250 mL saturated NaCl solution. Now, carefully pour more water down the side of the cylinder without stirring until the cylinder is nearly full. Now drop an egg into each container. In pure water, the egg falls. In the salt solution, the egg will remain suspended somewhere in the bottom half of the cylinder where the density of the solution equals that of the egg.

Remarks

One way to introduce this demonstration is to ask if any students have ever swum in the Great Salt Lake or the Dead Sea. If so, they can attest to the difference in buoyancy between those very salty "oceans" and fresh water.

Maybe students will have noticed the phenomenon illustrated in *Part A* at picnics where large trash cans or barrels are often filled with ice and canned drinks. If there is freedom of movement, the sugared drinks will be on the bottom and diet drinks on top. The greater the sugar content, the deeper the can sinks.

Demonstration 3: Osmotic Pressure

Purpose

In this activity, students will observe increased osmotic pressure as a saturated solution of sodium chloride is diluted by distilled water passing through a membrane causing the water level of a thistle tube to rise.

Materials

Ring stand and clamp
Beaker, 400-mL and 150-mL
Semipermeable membrane (dialysis tubing or cellophane)
Saturated salt water (40 NaCl per 100 mL solution)
Thistle tube or similar tubing

Procedure

Fill 400-mL beaker approximately 3/4 full of distilled water. Put saturated NaCl solution inside of thistle tube (which has membrane over the large open end) until saturated NaCl solution is just above the distilled water level in the beaker (see Figure 15). Mark initial level on Day 1 and mark final level the next day. *[NOTE: To fill the thistle tube, place piece of cellophane in a 150-mL beaker and depress it to the bottom with thistle tube. Remove thistle tube and fill depression with NaCl (sat.). Replace thistle tube and allow to fill with solution. Secure cellophane around bottom of thistle tube with thread or rubber band.]*

The distilled water passed through the membrane and diluted the saturated sodium chloride solution. As this happened, pressure increased, the fluid level inside of the thistle tube increased, and the fluid level in the thistle tube rose.

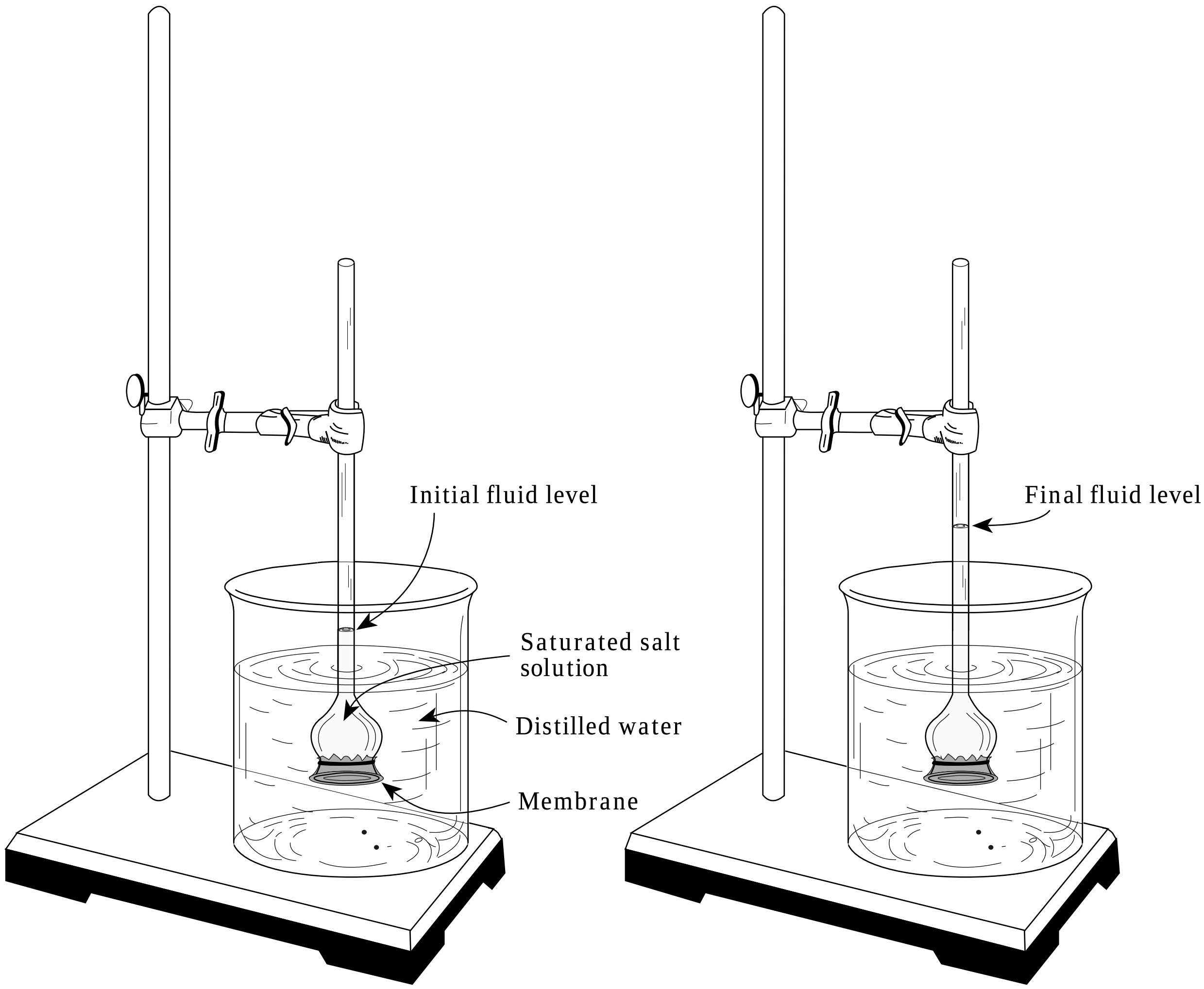


Figure 15. Osmotic pressure apparatus.

Extensions

1. Evaporate some seawater and look at the remaining solids under a microscope.
2. Again, using a microscope, look at plant cells and what happens when they are immersed in distilled water *vs.* salt water.

Remarks

Osmosis is used to desalinate water. In light of the severe water shortage in certain parts of the world, there is great interest in using osmosis to purify water.

GROUP AND DISCUSSION ACTIVITIES

Counterintuitive Examples

1. Water can be purified by passing through a filter. *[Some impurities or substances found in water can be filtered. Suspended solids can be removed with filter paper; some organic compounds can be absorbed on pulverized charcoal. Soluble salts are not so easily removed.]*

2. All salts dissolve more in warm water than in cold water. *[While this fact is true for many salts, it is not universal. For example, when NH_4NO_3 dissolves in water, the reaction is endothermic, meaning that heat is absorbed during the reaction. The surrounding air and solution get colder as they supply this heat.*

$$Heat + NH_4NO_3(s) + H_2O(l) \rightarrow NH_4^+(aq) + NO_3^-(aq)$$

According to LeChatelier's Principle raising the temperature of the system, which is adding more of the reactant heat, will cause more NH_4NO_3 to dissolve.

In contrast, when $MgSO_4$ dissolves in water, the opposite effect is noted; the surroundings get warmer because heat is produced.

$$MgSO_4(s) + H_2O(l) \rightarrow Mg^{2+}(aq) + SO_4^{2-}(aq) + Heat$$

In this case, raising the temperature shifts the equilibrium to the left so that less $MgSO_4$ dissolves in hot water than in cold.

As a side note, mention to students that NH_4NO_3 is the salt used in many first-aid cold packs, while $MgSO_4$ is used in first-aid hot packs.]

3. Gases dissolve better in warm water than cold. *[Open a cold can of soda and one at room temperature. Which one loses its carbonation more quickly? (The warmer one because CO_2 is less soluble at higher temperatures.)]*

Pictures in the Mind

1. Distribution of the world's water supply (see *Appendix*).
2. Seawater contains an average of 35,000 parts per million of dissolved solids. In a cubic mile of seawater, weighing 4.7 billion tons, there are about 165 million tons of dissolved matter, mostly chlorine and sodium (see *Appendix*).

Language of Chemistry

TIPS FOR THE TEACHER

boiling point temperature at which the vapor pressure of a liquid is equal to the external pressure.

boiling point elevation a colligative property in which the boiling point of a solution is raised above that of the pure solvent according to the number of solute particles present.

buffer a solution that resists change in pH when either OH^- or H^+ is added.

chlorinity the total amount of dissolved halide ions (Cl^-, F^-, Br^-, I^-) present in a solution such as seawater; usually expressed in mol L^{-1}, ppt or ppm.

colligative properties physical properties of a solution (vapor pressure lowering, boiling point elevation, freezing point depression, osmotic pressure) that are different for a solution than for a pure solvent, according to the number of solute particles, and not their identities.

freezing point the temperature where the solid and liquid phase of a substance coexist; also called melting point.

freezing point depression a colligative property in which the freezing point of a solution is lowered below that of the pure solvent according to the number of solute particles present.

melting point see freezing point.

osmosis the flow of solvent into a solution through a semi-permeable membrane.

osmotic pressure a colligative property—the pressure which must be applied to a solution to stop osmosis.

parts per billion (ppb) a unit of concentration. One ppb is one part of solute per billion parts of solution. For example, if an air sample contained 1 ppb Hg vapor then there is 1 mL Hg(g) in 10^9 mL air or 1 mL Hg in 10^6 L of air.

parts per million (ppm) one ppm is one part of solute per million parts of solution.

parts per thousand (ppt) one ppt is one part of solute per thousand parts of solution.

salinity total concentration of dissolved material (all ions), usually expressed in mol L^{-1} or ppt.

Common Student Misconceptions

Gold can be mined from seawater. While seawater does contain a small amount of gold (0.011 ppb), it is not economically feasible to separate it. Have students calculate how much gold there is in the oceans, which contain approximately 3 x 10^{19} L of water (see *Counterintuitive Examples*).

Decision Making

1. How well must sewage be treated before dumping in the ocean? Need it be pure water when it leaves the wastewater treatment plant or is some amount of dissolved material more ecologically sound?
2. Effect of global warming on the ocean. As scientists worry about increasing CO_2 and CH_4 concentrations in the atmosphere, what are the possible effects on the ocean?
3. Additional CO_2 in the atmosphere can lead to greater quantities dissolved in seawater. What effects might occur?

History: On the Human Side

In the Bible, the cities of Sodom and Gomorrah are associated with sin and destruction. Traditionally, these cities were located on the large plain south of the Dead Sea, where grotesque salt pillars (a result of the rapid evaporation of the briny waters) can still be seen. We remember that as Lot fled the destruction of these cities, his wife looked back and turned into a pillar of salt. What do you think about this story and its geographical setting?

Humor: On the Fun Side

1. The children of the Bluestone family were playing a game of hide-and-go-seek, and all were enjoying the game save the youngest child who was always the first to be discovered. When asked why this was so, he replied, "I guess I just don't know how to hydrate."

   CHEM 13 NEWS, December 1984, p. 824
2. CH_2O is the formula for seawater.
3. Message on a T-shirt:

   Front: What's $(H_2O)_4$?
   Back: Drinking.
4. $\frac{[NaCl(aq)]^2}{C_7}$ "Sailing, sailing, over the seven seas."
   (Saline, saline, over the seven C's.)
   CHEM 13 News, November 1976, p. 1107

5. **AN ODE TO WATER** *(To be sung to the Mickey Mouse Club tune)*

   What's the solvent molecule, that's found in you and me?
   DoubleU-A-T-E-R, as bent as it can be.

   If it could be linear, then gases we would be.
   DoubleU-A-T-E-R, just right for you and me.

   Hydrogen,
   Oxygen,
   You give it just the right polarity.

   We applaud its structure, with its subtle symmetry.
   DoubleU-A-T-E-R, as bent as it can be.

   CHEM 13 NEWS, May 1988, p. 2

6. Word Search (see *Appendix* for master copy)

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B C Y U K X R Y T I N I L A S W T
O U V N T Y X Z Z N Z N E I Q B N
I Q A G L E K E E T T L K M Y E I
L C C N S C V P C G E L Y G D V O
I H J F U W U I F C P U V E K O P
N L T T G J T Q T X G G X Q S H G
G O M B H O F R L A G B U R I W N
P R I B M B O T I L G C R Q S H I
O I W S R L L C S U G I M P O N Z
I N O K Y S Y J Z M C B L X M W E
N I P T U I N L B Y B P G L S D E
T T E E K P P V K N D F D J O K R
T Y T Z V G M R E F F U B A Z C F
```

   Words about the concepts in this module can be obtained from the clues given. Find these words in the block of letters:

   1. Total concentration of dissolved material (all ions), usually expressed in mol/L.
   2. Flow of solvent into a solution through a semi-permeable membrane.
   3. Total amount of dissolved halide ions present in a solution such as seawater.
   4. Solution that resists change in pH when either OH^- or H^+ is added.
   5. Adjective for physical properties of a solution that are different from those of a pure solvent and depending on the number of particles dissolved.
   6. Pressure that must be applied to a solution to stop osmosis.
   7. Temperature where the solid and liquid phase of a substance coexist (2 words).
   8. Temperature at which the vapor pressure of the liquid is equal to the external pressure (2 words).
   9. Unit of concentration abbreviation meaning one part of solute per billion parts of solution.
   10. Substance whose solution in water conducts electricity.

   Answers: 1. SALINITY 2. OSMOSIS 3. CHLORINITY 4. BUFFER 5.COLLIGATIVE 6. OSMOTIC 7. FREEZING POINT 8. BOILING POINT 9. PPB 10. ELECTROLYTE

7. See cartoons at end of module.

MEDIA

1. The *World of Chemistry* videotapes "No. 12: Water," "No. 17: The Precious Envelope," and "No. 18: The Chemistry of the Earth," are particularly appropriate for this module. World of Chemistry Videocassettes. Annenberg/CPB Project, P.O. Box 1922, Santa Barbara, CA 93116-1922; (800) 532-7637; World of Chemistry Series, Atlantic Video, 150 South Gordon Street, Alexandria, VA 22304; (703) 823-2800 or QUEUE Educational Video, 338 Commerce Drive, Fairfield, CT 06430; (800) 232-2224.

2. Videodiscs published by *JCE:* Software, a publication of the *Journal of Chemical Education,* Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706-1396: (608) 262-5153 (voice) or (608) 262-0381 (FAX).

   a. "Water's Structure," "Detergent Action," "The Hydrologic Cycle" and "Acid Rain and Limestone," four chapters on *The World of Chemistry: Selected Demonstrations and Animations*: Disc II (double sided, 60 min.), Special Issue 4.

   b. "Water and Ice," "A Solution with Water," "Alcohol Dissolves in Water," and "Water and Oil," four chapters on *The World of Chemistry: Selected Demonstrations and Animations*: Disc I (double sided, 60 min.), Special Issue 3.

Links/Connections

Within Chemistry

1. See module on *Solubility and Precipitation*.
2. The volume of the earth's oceans is 1.4 x 10^{21} L, with a concentration of sodium chloride of 31.3 g per kg of seawater. Total number of moles of sodium chloride in the ocean is 7.5 x 10^{20}, which is equivalent to 4.4 x 10^{22} g or 4.9 x 10^{16} tons.

Between Chemistry and Other Disciplines

Biology (saline solutions and solution concentrations)
Geology
Economics
Physics (physical separations)
Oceanography

Constituent		g/kg Seawater	Percent by weight
Chloride	Cl^-	18.980	55.04
Sodium	Na^+	10.556	30.61
Sulfate	SO_4^{2-}	2.649	7.68
Magnesium	Mg^{2+}	1.272	3.69
Calcium	Ca^{2+}	0.400	1.16
Potassium	K^+	0.380	1.10
Bicarbonate	HCO_3^-	0.140	0.41
Bromide	Br^-	0.065	0.19
Boric acid	H_3BO_3	0.026	0.07
Strontium	Sr^{2+}	0.013	0.04
Fluoride	F^-	0.001	0.00
	Total	**34.482**	**99.99%**

Dissolved constituents of 1 kilogram of seawater (Chlorinity = 19%)

Constituent		Percent by weight
Carbonate	CO_3^{2-}	35.15
Calcium	Ca^{2+}	20.39
Sulfate	SO_4^{2-}	12.14
Silicon Dioxide	SiO_2	11.67
Sodium	Na^+	5.79
Chloride	Cl^-	5.68
Magnesium	Mg^{2+}	3.41
Oxides	Fe_2O_3,Al_2O_3	2.75
Potassium	K^+	2.12
Nitrate	NO_3^-	0.90
	Total	**100.00%**

Dissolved constituents of river water (average)

To the Contemporary World

Personal

1. Kelp (seaweed) is harvested to provide many products. The most important of these is probably algin, or sodium alginate, a polysaccharide with gelling properties. It finds uses in ice cream and soft drinks.
2. The similarities between seawater and blood:
   - Both composed of mostly water.
   - Both have similar densities.
   - Both contain similar percentages of dissolved salts.
   - Both have similar pH values.
   - Both are slightly basic.

Community

Obviously, teachers in communities on or near an ocean (or the Great Salt Lake) can plan many field trips and take advantage of experts in the area. Teachers in inland cities can use museums and museum directors as resources. Marine biologists and chemists are hired by aquariums (Seaworld and Disney Epcot Center, for example) to maintain balanced ecosystems in display tanks.

Societal (Science/Technology/Society; Current Events)

1. Increasingly, the desalinization of seawater looks attractive as a source of fresh water for populations of arid regions.
2. Sea salts are "farmed" in many areas by drawing the seawater into evaporating ponds.
3. The sea is a source for many very important chemical separations. It is the largest source of Br^- salts, which are used to make Br_2.
4. A discussion of some methods of desalination that are currently used:
   - **Distillation**. In a closed system, evaporation can remove salt from seawater. Upon condensation this fresh water can be isolated from the seawater and collected.
   - **Freezing**. Because salt interferes with the hydrogen bonding that occurs as water freezes, water will crystallize first where the hydrogen bonding is not inhibited. Therefore, as ice freezes it excludes the salt from the crystal, effectively purifying itself.
   - **Reverse osmosis**. A semipermeable membrane (a membrane permeable to H_2O molecules but not to ions or larger molecules) can separate fresh water from seawater. The fresh water, by osmosis, passes into the seawater and dilutes it. The level on the seawater side rises since more H_2O molecules enter this side than leave. In order to force more H_2O molecules back into the fresh water side an external force in excess of the osmotic pressure of normal seawater (24.8 atm) is exerted on the seawater side. More fresh water is forced back into the fresh water side than diffused into the seawater. The net result: production of fresh water.
   - **Electrodialysis**. Very similar to reverse osmosis. A semipermeable membrane selectively isolates the salt from the fresh water. An electrical potential difference speeds the process by attracting the ions.

5. Hydrocarbons in the form of oil and natural gas are being produced from wells on the continental shelves in many areas of the world. Some of the issues raised by such drilling:
   - The size of the oil reservoir.
   - Active earthquake faults.
   - Prevailing winds and currents in the area of a drilling platform.
   - Ecological, social, and economic impacts of drilling activities on the community.
   - Impact of drilling with current oceanic resources such as fishing and recreation.
6. Manganese nodules on the ocean floor contain large amounts of iron and manganese.
7. Phosphate compounds have accumulated on submarine terraces on many continental shelves.
8. Potential gold and diamond deposits lie at the mouths of large rivers.
9. Muds near hot springs on the ocean ridges are rich in metallic minerals.
10. Energy can be derived from the sea by tides, waves, and thermal differences.
11. Major and minor ions in seawater are present in living systems in the same relative concentrations. Does this give any credence to the hypothesis that life originated in the oceans?

Extensions and Projects

1. Discuss the chemistry and critical features of aquarium water. Why do some fish live only in fresh water while some live only in salt water? What physiological adaptations do salmon make as they move from fresh water to seawater?
2. The hydrothermal vents in the trenches of the ocean exhibit some fascinating chemistry that could be investigated.

References

Module drafted by Joseph Baron, Marvin Blevins, and Barbara Sawrey, the California team.

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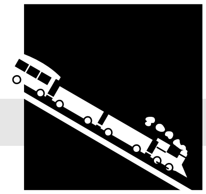
Appendix



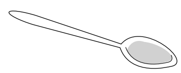
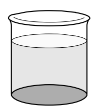
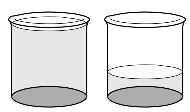
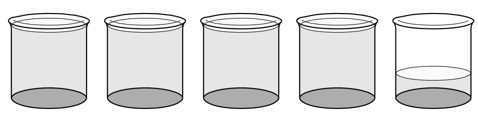
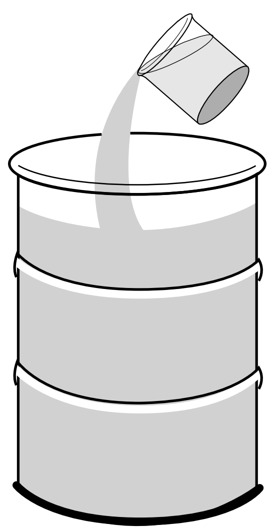
- **Transparency Masters**
  1. The Properties of Water
  2. Water Supply Distribution
  3. Dissolved Solids in Seawater
  4. Word Search
- **Humor**

The Properties of Water

Property	Compared to other substances
• Quantity present on earth's surface.	• Three times as abundant as all other substances combined.
• Dissolving ability	• Dissolves more substances in greater quantities than any other common liquid.
• Surface tension	• Highest of all common liquids.
• Conduction of heat	• Highest of all common liquids, except mercury.
• Heat capacity—quantity of heat required to raise temperature of 1 g of substance 1 °C.	• Highest of all common solids and liquids.
• Latent heat of fusion—quantity of heat gained or lost per unit mass by substance changing from solid to liquid or liquid to solid phase without accompanying temperature rise.	• Highest of all common solids and liquids.
• Latent heat of vaporization—quantity of heat gained or lost per unit mass by substance changing from liquid to gas or gas to liquid phase without an accompanying temperature rise.	• Highest of all common substances.
• Transparency	• Relatively great for visible light.
• Sound transmission	• Transmits sound well, compared to other liquids.

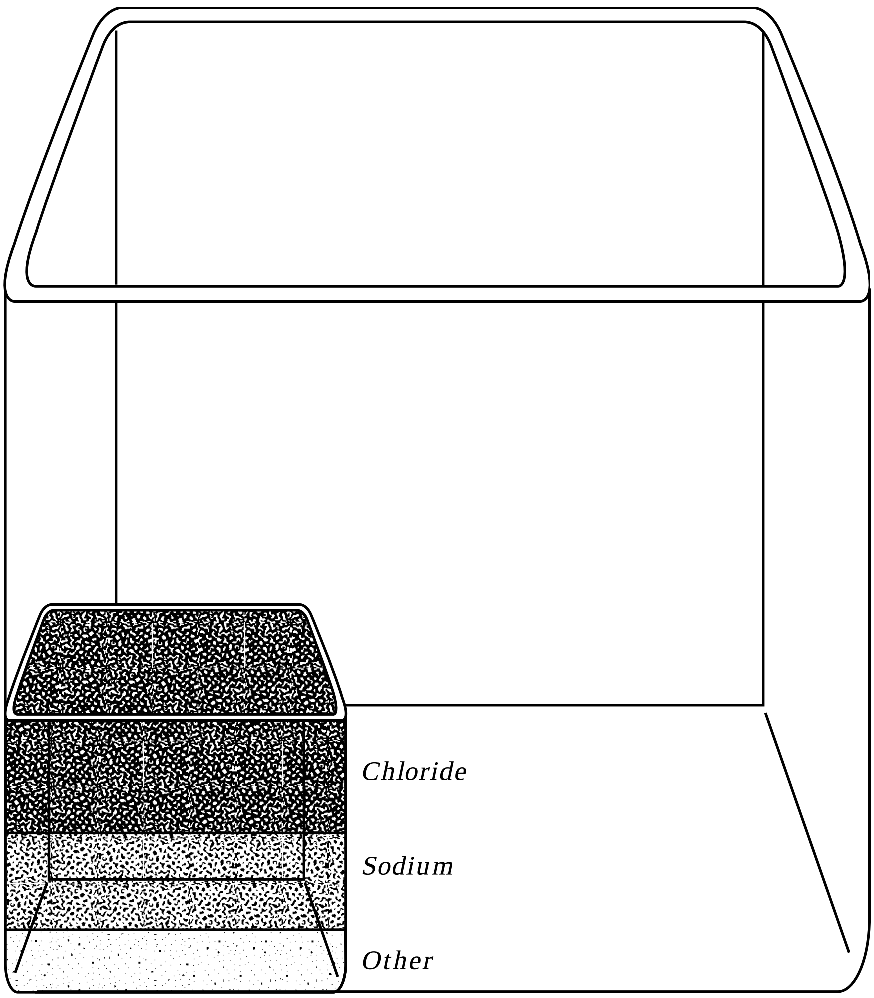
Water Supply Distribution

What if the world's total water supply were in a 200-L (about 55 gal) drum, then…

Source	***Representation***	***Percentage***
Rivers		0.0001
Atmospheric moisture		0.001
Lakes		0.016
Groundwater		0.61
Glaciers and ice caps		2.24
Ocean water		97.1

Adapated from ChemCom: Chemistry in the Community. (1988). Dubuque, IA: American Chemical Society, Kendall/Hunt Publishing Co.

Dissolved Solids in Seawater

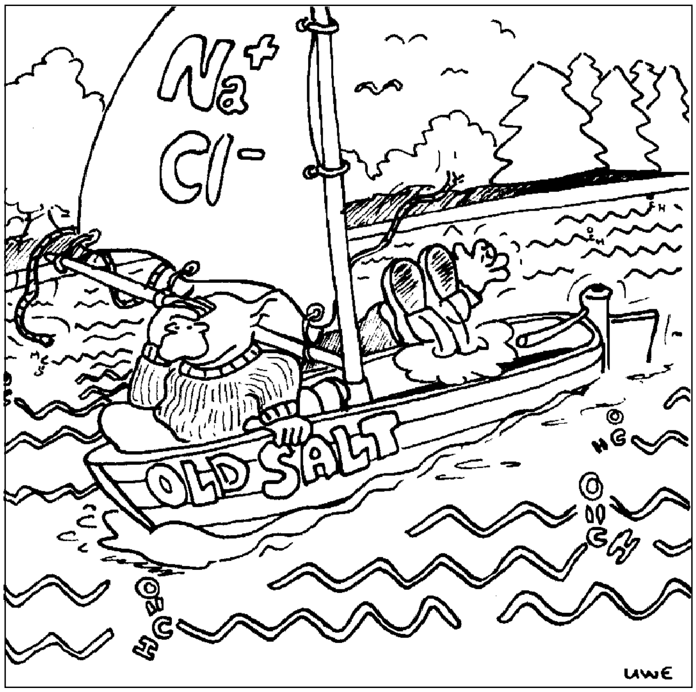


Word Search

B	C	Y	U	K	X	R	Y	T	I	N	I	L	A	S	W	T
O	U	V	N	T	Y	X	Z	Z	N	Z	N	E	I	Q	B	N
I	Q	A	G	L	E	K	E	E	T	T	L	K	M	Y	E	I
L	C	C	N	S	C	V	P	C	G	E	L	Y	G	D	V	O
I	H	J	F	U	W	U	I	F	C	P	U	V	E	K	O	P
N	L	T	T	G	J	T	Q	T	X	G	G	X	Q	S	H	G
G	O	M	B	H	O	F	R	L	A	G	B	U	R	I	W	N
P	R	I	B	M	B	O	T	I	L	G	C	P	Q	S	H	I
O	I	W	S	R	L	L	C	S	U	G	I	M	P	O	N	Z
I	N	O	K	Y	S	Y	J	Z	M	C	B	L	X	M	W	E
N	I	P	T	U	I	N	L	B	Y	B	P	G	L	S	D	E
T	T	E	E	K	P	P	V	K	N	D	F	D	J	O	K	R
T	Y	T	Z	V	G	M	R	E	F	F	U	B	A	Z	C	F

Words about the concepts in this module can be obtained from the clues given. Find these words in the block of letters:

1. Total concentration of dissolved material (all ions), usually expressed in mol/L.
2. Flow of solvent into a solution through a semi-permeable membrane.
3. Total amount of dissolved halide ions present in a solution such as seawater.
4. Solution that resists change in pH when either OH^- or H^+ is added.
5. Adjective for physical properties of a solution that are different from those of a pure solvent and depending on the number of particles dissolved.
6. Pressure that must be applied to a solution to stop osmosis.
7. Temperature where the solid and liquid phase of a substance coexist (2 words).
8. Temperature at which the vapor pressure of the liquid is equal to the external pressure (2 words).
9. Unit of concentration abbreviation meaning one part of solute per billion parts of solution.
10. Substance whose solution in water conducts electricity.



Saline on Decanal

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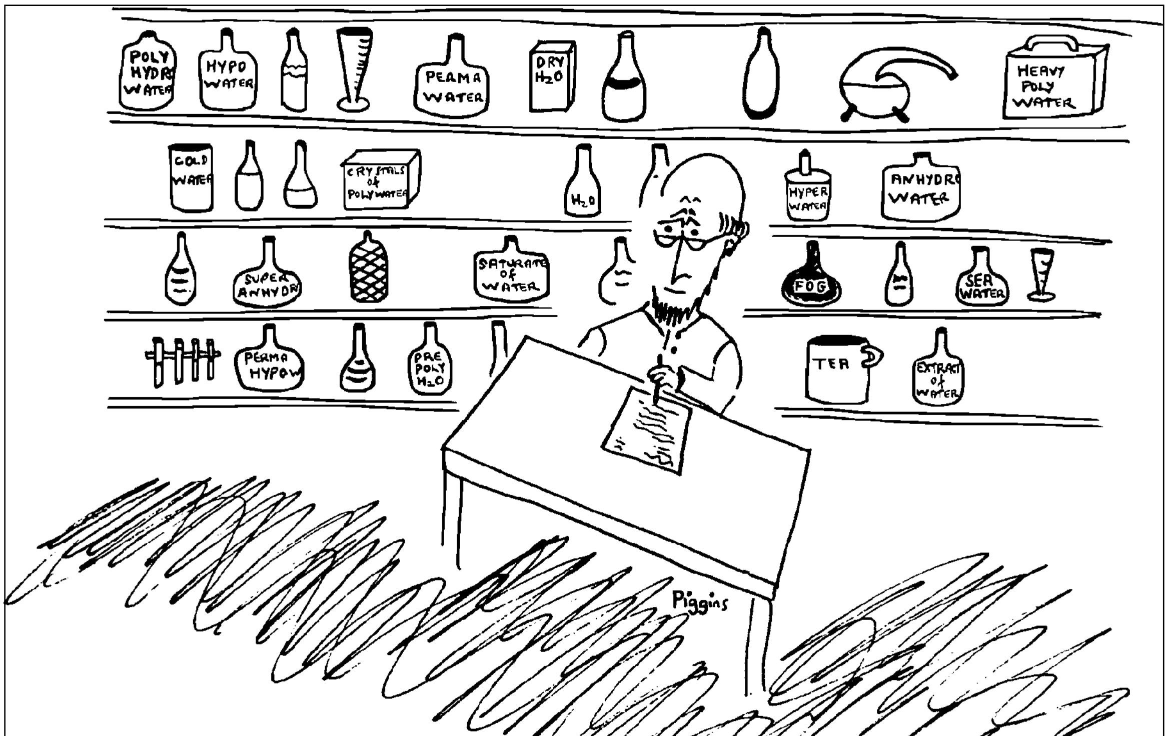

Dear Sir:

I understand that you have recently published an account of a new type of water ....

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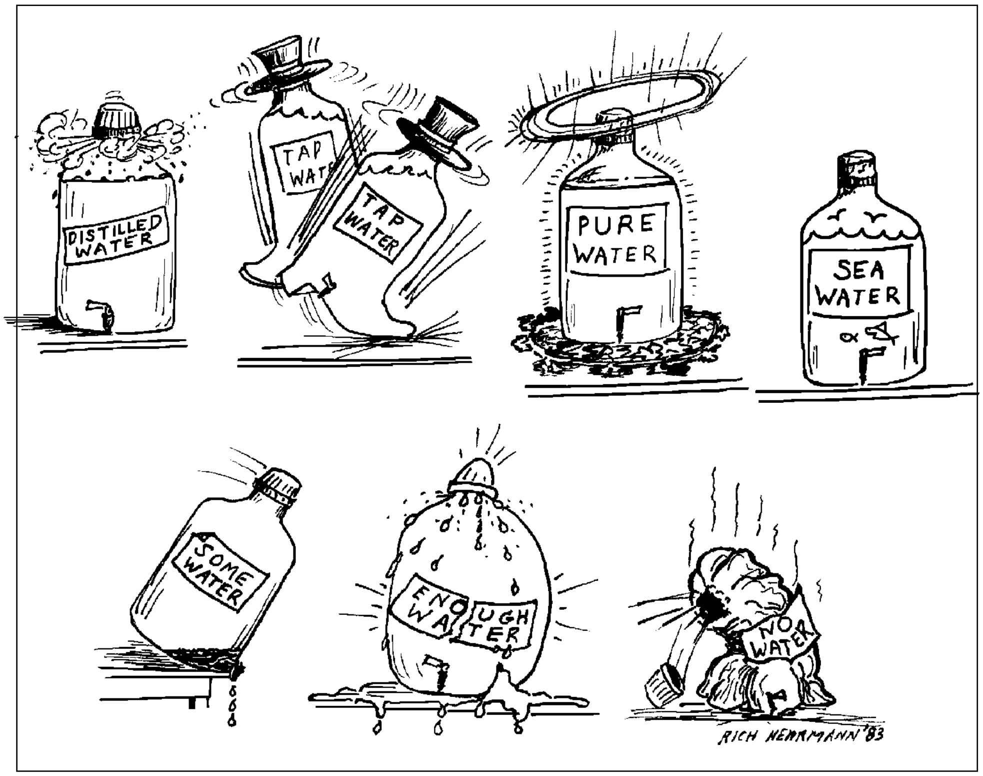
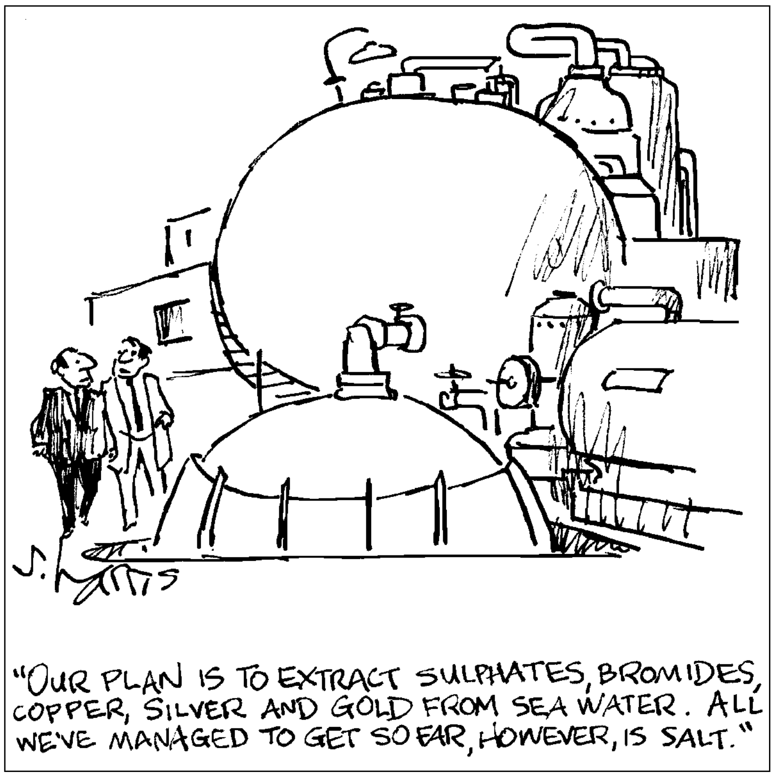


CHEM 13 NEWS, April 1983, p. 1. Reprinted with permission.


DESALINATION PLANT
"JUST IN CASE IT DOESN'T WORK, WE'D LIKE YOU TO COME UP WITH SOME USES FOR TEN MILLION GALLONS OF SALT WATER EVERY DAY."


"OUR PLAN IS TO EXTRACT SULPHATES, BROMIDES, COPPER, SILVER AND GOLD FROM SEA WATER. ALL WE'VE MANAGED TO GET SO FAR, HOWEVER, IS SALT."