1.3.6 DENSITY OF LIQUIDS

Concepts to Investigate: density gradient, specific gravity

Materials: Part 1: vegetable oil, glycerol, corn syrup, liquid detergent, isopropyl alcohol, Part 2: food coloring, flask, overhead transparency or note card. Part 3: Plastic drinking straw, modeling clay or paraffin, sand, beaker, glycerin, olive oil, milk, salt.

Principles and Procedures:

Part 1: Density gradient: The following household liquids vary in density from about 0.9 g/mL to about 1.4 g/mL: vegetable oil, glycerol, water, corn syrup, detergent, and isopropyl alcohol. In this activity you will be attempting to rank them in order of increasing density. Use a mechanical pipet or eye dropper to place a small amount of one fluid onto the surface of another (Figure U). To avoid turbulence, you should release the liquid from the pipet as slowly as possible, preferably down the side of the test tube. If the fluid sinks, then it has greater density than the fluid in which it has been placed, but if it floats, it has a lesser density. Repeat the procedure with other pairs of liquids until you believe you have established a density ranking. Once you have done so, use the pipet to construct a 6 tier density gradient in a test tube as shown in Figure V. If your density scale is correct, there will be only minimal mixing of the liquids. Label the fluids in the diagram.

Do the following to calculate the densities of each of these liquids. First, determine the mass of a dry graduated cylinder. Pour the first liquid into the cylinder, measure its volume, and determine its mass. The mass of the fluid is the difference between the mass of the full cylinder and the mass of the dry cylinder. The density is simply the mass divided by the volume (d=m/v). Calculate the density of each fluid and compare your values with the density gradient. Is the densest fluid on the bottom and the least dense fluid on top?

Part 2: The effect of temperature on density: Place a couple of drops of blue food coloring in each of two identical Erlenmeyer flasks. Fill the flasks to overflowing with cool tap water, mixing to distribute the food coloring evenly throughout. Repeat the procedure with two flasks of warm tap water, only this time add red food coloring. Place a plastic square cut from an overhead transparency on top of one of the warm flasks and carefully invert the flask and place it on top of a cool flask (Figure W). Carefully remove the sheet and watch for mixing. Repeat the procedure, but this time place the remaining cool flask on top of the warm one. Which fluid has a greater density, the warm water or the cool water?

Part 3: Specific gravity: Buoyancy is dependent upon the density of a fluid. The denser a fluid, the greater the buoyant force per unit volume displaced. Since the density of ocean water is 1.025 g/mL, while that of fresh water is only 1.000 g/mL, an equal displacement of salt water will produce a greater buoyant force than fresh water. For this reason, boats float slightly higher in salt water.

Since the buoyancy of an object is dependent upon the density of the fluid in which it is floating, it is possible to make an instrument that measures fluid density on the basis of how high the instrument floats. Such an instrument is known as a hydrometer and can be constructed from a plastic drinking straw as illustrated in Figure X. Seal one end of a straw by plugging it with modeling clay and paraffin (hot candle wax) as shown. Hold the straw upright in water while you pour a small amount of sand into the open end of the straw. Add enough to stabilize the straw, but not enough to sink it! Carefully note the water line and mark this as 1.00 with a fine tipped permanent marker, since the density of water is 1.00 g/mL.   To provide another reference point, float the hydrometer in olive oil and mark the level as 0.92. The density of olive oil is 0.92 g/mL, or 92% the density of water, so we say it has a specific gravity of 0.92. The specific gravity is merely the ratio of a substance's density relative to water. Using these two points you should be able to generate an approximate scale of specific gravity. Using your hydrometer, determine the approximate specific gravity of glycerin and milk. If you do not have these liquids, you may still observe how the hydrometer works by slowly adding salt to the beaker and watching the hydrometer rise.

Questions

(1) Assume that a cylinder was filled with mercury (a liquid metal with density 13.6 g/mL), water (1.0 g/mL) and maple syrup (1.4 g/mL). Which fluid would occupy the bottom position, and which the top? Describe what would happen to each of the following items if placed in this cylinder: a block of pine wood (0.8 g/mL), a lead fishing weight (11.4 g/mL), a copper coin (8.9 g/mL), a gold ring (19.3 g/mL), and a block of ebony wood (1.2 g/mL).

(2) In part 2 your probably noticed the development of a purple color. What is the temperature of the purple water relative to the red and blue?

(3) If you have ever gone diving in a lake or ocean, you may have noticed the temperature drop dramatically as you go down only 1 or 2 meters. Explain.

(4) Plankton are small or microscopic organisms that float or drift near the surface of ocean or lake waters. They are the base of the aquatic food chain, and therefore extremely important to all other aquatic life. Plankton depend upon nutrients, which typically are

denser than water and sink. If water is undisturbed, it is possible for so many nutrients to sink to the bottom that plankton can no longer live, and thus no other aquatic life as well. Fortunately, changes in temperature can cause a mixing of water that brings nutrients back up to the surface . Explain..

(5) Hydrometers are used to determine the density of water in car radiators. Since density varies as a function of the amount of anti-freeze (ethylene glycol) added, it is possible to determine the percentage of antifreeze in the radiator and the temperature at which it would freeze. Knowing the specific gravity of ethylene glycol to be 0.958, would a radiator containing fluid with a specific gravity of 0.976 or 0.989 be better prepared for cold weather? Explain.

1.3.7 DENSITY OF SOLUTIONS

Concepts to Investigate: Density, concentration.

Materials: Part 1: Green and ripe tomatoes; Part 2: Cans of diet and regular soft drinks.

Principles and Procedures: Many of us enjoy maple syrup on our pancakes, French toast, or waffles. This syrup comes from the sap of maple trees in the Northeastern United States and Southeastern Canada. Native Americans learned how to collect the sweet sap of the sugar maple by cutting the bark and then collecting the sap that drains out of the wound in the late winter and early spring. Early colonists in these regions learned how to make syrup and sugar from this sap by boiling off the water. Millions of liters of maple syrup are produced in this manner each year and sold throughout the world. Maple tree farmers sell the sap to refiners, who measure the sugar content of the sap on the basis of density. The denser the sap, the greater the sugar content and the more syrup or sugar can be made. This principle is true for other solutions as well: the more dissolved solutes, the denser the solution. You will use this principle to investigate the quantity of dissolved solutes in fruits and soft drinks.

Part 1: Separating Ripe from Green Tomatoes: Approximately 75% of the entire American tomato crop is processed into juice, canned tomatoes, sauces, pastes, and catsup. Before tomatoes can be processed, the green tomatoes must be removed so only the ripe ones will remain for processing. The ripeness of a tomato can be determined not only by color, but also by density. When tomatoes are placed in water, they either float or sink depending upon their ripeness (Figure Y). Which are denser, green or ripe tomatoes? Place ripe and green tomatoes in an aquarium or sink filled with water and determine which are denser. Most tomatoes are separated by machine rather than by hand. How would you design a machine to separate green from ripe tomatoes?

Part 2: Diet vs. Regular Soft Drinks: Do you get "more" for your money when purchasing regular soft drinks or diet soft drinks? Examine the labels of regular and diet varieties of the same soft drink. In most situations they have exactly the same volume (e.g. 355 mL), but not the same mass. Place cans of diet and regular soft drink (of the same brand) in an aquarium or large pail of water and observe what happens (Figure Y). Which soft drink has the greater density? Calculate the densities (Figure Z) of the regular and diet drinks by determining the mass of the fluid (the difference in mass between a full and empty can) and dividing by the volume (printed on the side of the can). Which has greater density?

Questions:

(1) Which have greater density, ripe tomatoes or green tomatoes? Which has more dissolved solutes?

(2) Draw a simple design for a machine that can be used to separate green tomatoes from ripe ones.

(3) Which have greater density, regular or diet soft drinks? Which has more dissolved solutes?

(4) Examine the "nutrition facts" label on the side of the regular and diet soft drink cans. What dissolved solutes do they list? Which is the main solute that contributes to the difference in density between the two drinks?

(5) What is the density of the regular soft drink and the diet soft drink.

1.3.8 DENSITY OF SOLUTIONS: THE MYSTERY OF THE STRAIT OF GIBRALTAR

Concepts to Investigate: Density, salinity, concentration, currents.

Materials: Non-iodized salt, egg, food coloring, cake pan, tape, overhead transparency, paper punch, pepper, food coloring.

Principles and Procedures: The Mediterranean Sea (Figure AA) is a great expanse of water that stretches from the Atlantic Ocean on the west, to Asia on the east, and separates the African and European continents. Its name means "sea between lands" (*med*- means middle: e.g. median, *terra*- land; e.g. terrestrial). Historians have referred to this sea as the "incubator of Western Civilization" because the major civilizations of ancient Egypt, Israel, Phoenicia, Greece, and Rome had their beginnings on the shores of this sea. Prior to the development of the Suez Canal in 1869, the only link between the Mediterranean and the oceans of the world was through the Strait of Gibraltar, a 13 km (8 mi) wide strip of water connecting the western Mediterranean with the Atlantic Ocean.

When the Phoenician explorers and traders first sailed through the strait in approximately 800 BC they noticed a very strong current coming into the Mediterranean from the Atlantic. As later sea-faring people traveled through the Strait of Gibraltar, they also noticed a very strong current, approaching two meters per second in certain areas. As cartographers developed accurate maps of the Mediterranean, it became apparent that it was not connected to the ocean through any other points except the Strait of Gibraltar. This raised a very perplexing question: how can the water continually flow one way into the Mediterranean? Some people hypothesized that there was a major underwater "drain", and others hypothesized that the cartographers had simply not found another strait similar to Gibraltar where the water flowed out of the Mediterranean and into the ocean. What do you think? Try these activities and then generate your own hypothesis.

Part 1: Salt water vs. fresh water: Dissolve a couple of tablespoons of salt into a Erlenmeyer flask or similar container. Put a drop of food coloring into the salt water to distinguish it from fresh water. Fill another container with fresh water and cover the top with a note card or a small square of plastic cut from an overhead transparency. Carefully invert the fresh water on top of the salt water and remove the card or square (Figure BB). Observe the containers for two minutes. Is there much mixing between the fresh and salt water? Repeat the process placing the container with the salt water on top of the fresh water (Figure CC). On the basis of these observations, which appears to have a higher density, fresh water or salt water?

Part 2: Salinity and buoyancy: If the density of an object is less than the density of the fluid in which it is placed, the object will float. If the density of the object is greater than the density of the fluid, it will sink. Archimedes' principle states that an object is buoyed by a force equivalent to the weight of the water it displaces. Knowing this, what will happen to a ship or fish as it moves from saltwater to freshwater or vice versa? Place a fresh egg in a beaker of tap water, and record its position. Slowly stir salt into the beaker until the egg rises and is suspended above the bottom of the beaker but below the surface of the water (Figure DD). What should be added to raise the egg to the surface? What should be added to cause the egg to sink to the bottom once again? Try it!

Part 3: Solving the Mystery of the Strait of Gibraltar: Oceanographers have determined that the Mediterranean Sea loses three times as much water from evaporation as it receives from the rivers that flow into it. As water evaporates from the sea, salts are left behind, and the sea becomes saltier, but not as salty as it would be if there was no outflow of salty water. By making a model (Figure EE) of the Mediterranean Sea and the Strait of Gibraltar, it may be possible to solve the mystery. Construct a dam in the middle of the pan using plastic cut from an overhead transparency or similar divider. Using a paper punch, cut one hole near the top right of the divider (for surface currents) and one near the bottom left (for deep currents) as illustrated. Attach small pieces of paper to the ends of each of two pieces of Scotch tape to serve as non-sticking tabs. Seal the holes with the sticky part of the tape, and then position the divider in the middle of the pan using duct tape or other strong water-resistant tape. Identify one side of the cake pan "Mediterranean" and the other side "Atlantic". Dissolve approximately five times as much salt in one beaker as in the other. The amounts are not critical, but the beaker representing the Mediterranean should have substantially more salt. Alternatively, you may simply use tap water for the Atlantic and very salty water for the Mediterranean. Add green food coloring to the beaker with the saltier solution. Slowly pour the saltier solution into the Mediterranean side while simultaneously pouring the less salty solution into the Atlantic side so as not to put excessive pressure on the dike. Add pepper to the surface of the "Atlantic" side. Carefully remove the tape from the dividers and observe the movement of the food coloring and the pepper. Which way does the salty water travel? The less salty water? On the basis of your observations, can you explain why sailors must always contend with a strong in-flowing current at the Strait of Gibraltar?

Questions:

(1) Which has higher density, salt or fresh water? Explain.

(2) Major cargo ships sail up the Saint Lawrence Seaway from the Atlantic Ocean to the Great Lakes. If their ballast tanks are not adjusted, will the ships ride higher or lower when they move from the ocean to the fresh water seaway?
(3) What is your solution to the mystery of the Strait of Gibraltar? How can water apparently flow into the Mediterranean Sea, but not out?
(4) An estuary is the region in which the water from a river mixes with the tidal waters of the ocean. Estuaries are very rich ecosystems, supporting a wide variety of plant and animal life. Would you expect halophytic ("salt-loving") organisms to live closer to the surface or bottom of the water? Explain.
(5) Oil drillers often flood oil wells with salt water to increase production. Why?

1.3.6 Density of Liquids

Discussion: You may wish to introduce this section with the following two discrepant events.

Teacher Demonstration 1: Floating and Sinking Ice: Fill one beaker with water (1.00 g/mL), and another with isopropyl alcohol (0.79g/mL) and place them on the desk without telling students their contents. Place an ice cube in each. The ice cube (0.92g/mL) will sink in the alcohol, but will float in the water (Figure NN). Since both liquids are colorless, students may initially assume that they are both water and may be surprised to see the difference between the two beakers. You may then ask them to hypothesize about what could have caused the difference in behavior of the cubes. Water is unusual in that its solid phase (ice) is less dense than its liquid phase. You may contrast the behavior of solid and liquid water with solid and liquid paraffin (Figure OO). Heat paraffin until it melts, and then place a chunk of solid paraffin in the solution and students will observe it sink, indicating that paraffin is indeed denser as a solid than as a liquid.

Teacher Demonstration 2: A dynamic density gradient: Fill a beaker one fourth full with Karo® Syrup or other similar corn syrup. Slowly add vegetable oil on top until the beaker is three quarters full of liquid. Be careful not to mix the corn syrup and vegetable oil! Place a colored (add food coloring before freezing) ice cube on top of the oil. Ice is less dense than vegetable oil, so it floats. Liquid water, however, is denser than vegetable oil, but not as dense as corn syrup. As the ice cube melts, colored droplets of water fall through the oil layer and land on the syrup layer, creating yet another layer in the density gradient (Figure PP)!

Part 1: Density gradient: The densities of the six liquids are as follows:

isopropyl alcohol (colorless) (0.79g/mL)	detergent (green) (1.04g/mL)
vegetable oil (yellow) (0.90g/mL)	glycerol (colorless) (1.26g/mL)

water (colorless) (1.00g/mL)   corn syrup (brown) (1.37g/mL)

These fluids were selected because they are relatively safe household products that the students can relate to. Many older texts suggest a density gradient of mercury, dichloroether, water and oil. Although such a gradient is more dramatic and more stable (the fluids are mutually immiscible), we believe that the hazard of mercury and dichloroether is too great and should be avoided in the secondary school classroom.

Part 2: The effect of temperature on density: Although it is relatively easy to balance two similar flasks on top of one another as required in this lab, you may wish to do this as a teacher demonstration rather than a student activity due to the potential for spilling. At higher temperatures, molecules move faster, collide harder, move farther apart, and therefore occupy more space for the same amount of mass. Thus, the density (mass to volume ratio) of a fluid is generally inversely related to its temperature. Warm water is less dense than cool water (except at temperatures between 0°C and 4°C where the warmer water is denser), and will remain on top if placed there initially. The thermocline (plane between the warm and cool water) will be visible from the back of the class if you have used different food coloring as suggested. If the cool water is placed on top, it will descend rapidly as the warm water ascends. A purple color will rapidly develop indicating a mixing of the warm red water and cold blue water.

Answers:

(1) Mercury is the densest and would occupy the bottom of the column. Water is the least dense, and would rest upon the syrup which would be in the middle. The pine block (0.8 g/mL) would float on top of the water phase (1.0 g/mL), while the ebony wood (1.2 g/mL) would sink to the top of the syrup phase (1.4 g/mL). The copper coin (8.9 g/mL) and lead fishing weight (11.4 g/mL) would sink through the syrup and rest on the mercury (13.6 g/mL) while the gold ring (19.3 g/mL) would sink all the way to the bottom.

(2) The purple color was of intermediate temperature because it formed from a mixing of the warm red water and the cool blue water.

(3) Cold water is denser than warm water. The sun heats the surface of a lake or the ocean, and as the water warms it becomes less dense and continues to float on the top. As you dive down you cross a thermocline into colder, denser water that has received less of the sun's warming rays.

(4) During cold weather, the surface waters cool more than the deeper waters. The cooler, denser surface waters sink and are replaced by warmer waters from the deep that bring nutrients back to the surface as they rise.

(5) The radiator with a specific gravity of 0.976 has more anti-freeze than the one with a specific gravity of 0.976, and thus will freeze at a lower temperature.

1.3.7 Density of Solutions:

Discussion: Archimedes' principle states that an object will float if the buoyant force (the weight of the fluid displaced) exceeds the force of gravity upon it (the weight of the object). A can of regular soft drink contains approximately 40 grams of sugar, which increases the density of the fluid contents by approximately 10%. Since the weight of the can and fluid exceeds the weight of water it displaces, the can sinks. Most diet soft drinks contain an artificial sweetener known as aspartame, a substance that is about 200 times as sweet as sugar. Since aspartamine is extremely sweet, only tiny amounts are added to diet soft drinks, and the resulting increase in density is negligible. Students may wonder how the diet drink can float since it must be slightly denser than water because it has some dissolved solutes (sodium, asmpartamine), and the aluminum is surely denser than water. It can float because soft drinks are always packed with a little extra space to prevent them from spilling when opened. Since this space is filled with air and carbon dioxide, the density of the closed container is sufficiently reduced so that it will float in water. Ask your students if it is possible to raise the can of soft drink to the surface without touching it. After some discussion of possible techniques, add salt or sugar to the water and stir to dissolve. When sufficient salt or sugar has been added, the can will rise to the surface because the weight of the salt solution it displaces now is greater than its own weight.

Answers:

(1) Sugars are produced when a fruit ripens, increasing the density of the fruit. Therefore, the ripe tomatoes sink, while the green tomatoes float (Figure QQ).

(2) A variety of machines may be proposed, but the simplest will probably be one that places tomatoes in a vat of water and then "drains off" the denser, ripe tomatoes, or "scoops off" the less dense, green tomatoes.

(3) Regular soft drinks have greater density due the presence of dissolved sugar. Far less aspartamine (artificial sweetener) is added in diet drinks than sugar in regular drinks because aspartamine is approximately 200 times as sweet.

(4) Most regular soft drinks will list total carbohydrates (basically sugar) and sodium. Sugar is the solute that explains the higher density of regular soft drinks.

(5) Student values will vary depending upon the soft drinks used. Diet soft drinks may have a density of approximately 1.05 g/mL, while regular soft drinks a density of 1.08 g/mL. Students may be surprised to see that the diet soft drink floats even though it has a

density greater than that of water. Remind them that the density of the entire can of diet soft drink (can, soft drink and trapped gasses) will be less than 1.00 g/mL (the density of water) due to undisolved gaseous carbon dioxide trapped inside the can. In other words, the can is not completely full of soft drink, but rather contains a small amount of gas that decreases the density of the system.

1.3.8 Density of Solutions: The Mystery of the Strait of Gibraltar:

Discussion: An interesting discrepant event is to "suspend" an egg in the middle of in a beaker as shown in Figure RR. Although it is possible to produce a solution which has a density identical to the egg, this is very difficult. It is easier to make two layers of solution by placing a very concentrated solution at the bottom of a beaker, and fresh water at the top. (Add the fresh water as slowly as possible so as to not disturb the salty layer). If you slowly release the egg in the beaker, it will sink through the fresh water layer and come to rest on the dense, saline layer. The egg will stay suspended this way for hours. Don't tell your students how you were able to suspend the egg, and challenge them to suspend an egg as you have done. You may wish to challenge your students to calculate the density of each solution used.

Answers:

(1) Salt water is denser than fresh water because of the dissolved salt.

(2) Boats will float lower in the fresh water because it provides less buoyant force (it is less dense) than salt water.

(3) The Mediterranean Sea is saltier than the Atlantic due to large evaporative water loss in its arid climate. This water is denser than the water of the Atlantic, so it sinks to the bottom when in contact with the Atlantic waters at the Strait of Gibraltar. Less salty, less dense water from the Atlantic rushes in to replace the saltier water that is exiting. Thus, there is a strong surface current flowing into the Mediterranean, and another strong deep current flowing from the Mediterranean to the Atlantic. Figure SS illustrates the current that is generated in this activity to simulate what happens at the Straight of Gibraltar. Early travelers were unaware of the deep current and were therefore perplexed by this constant current into the Mediterranean.

(4) Halophytes tend to live deeper in the water because the fresh water from the river is less dense and tends to float on top of the denser, saltier water.

(5) The salt water is denser than the oil, and it sinks to the bottom, buoying the oil to the surface.