I. Objectives

1. Investigate the relationships among mass, volume, and density.
2. Determine how temperature changes, salt, and alcohol affect the density of water
3. Calculate the density of an unknown material.

II. Introduction

This lab utilizes glassware and hot water. You must wear closed-toed shoes during this entire lab and goggles when working with alcohol and hot water.

Density can be determined by dividing the mass of an object by its volume. The volume of irregularly shaped objects can be determined by placing them in a graduated cylinder and calculating the change in volume.

An object will sink if its density is greater than the density of the liquid in which it is placed and will float if its density is lower. The density of the liquid can be changed by altering its temperature and its composition.

III. Calculations

Part 1 Objects

Density is calculated using the equation:

$$\rho = \frac{m}{V}$$

Part 3 Density Rod II

You will measure the length L of the density rod and use it, as well as the distance x that the rod extends into the alcohol and the distance $L - x$ that it extends into the water to determine the density of the rod.

Lengths:

L	length of density rod
x	length of density rod in oil
$L - x$	length of density rod in water
r	radius of density rod

Area:

$A = \pi r^2$ area of density rod

Volumes:

$V_o = Ax = \pi r^2 x$ volume of oil displaced by density rod

$V_w = A(L - x) = \pi r^2 (L - x)$ volume of water displaced by density rod

$V_r = AL = \pi r^2 L$ volume of density rod

$V_r = V_o + V_w$ volume of density rod

Weights:

$W_o = m_o g = \rho_o V_o g = \rho_o (\pi r^2 x) g$ weight of displaced oil,
substitution for V_o

$W_w = m_w g = \rho_w V_w g = \rho_w \left[\pi r^2 (L - x)\right] g$ weight of displaced water
substitution for V_w

$W_r = W_o + W_w$ weight of density rod

$W_r = m_r g = \rho_r V_r g = \rho_r (\pi r^2 L) g$ substitution for V_r

Pressures:

$P_o = \rho_o g x$ pressure exerted by oil

$P_w = \rho_w g (L - x)$ pressure exerted by water

$F_B = W_r$ buoyant force = weight of density rod

$F_B = W_o + W_w$ buoyant force =
weight displaced oil +
weight displaced water

$F_B = P_w A - P_o A$ section 11.6

$W_r = P_w A - P_o A$ substitution

$$\rho_r(\pi r^2 L)g = \rho_o(\pi r^2 x)g + \rho_w\left[\pi r^2(L-x)\right]g$$

substitution

$$\rho_r L = \rho_o x + \rho_w(L-x)$$

cancel out $\pi r^2 g$

If L, x, ρ_o, and ρ_w are known then the density ρ_r of the density rod can be calculated:

$$\rho_r = \frac{\rho_o x + \rho_w(L-x)}{L}$$

<u>Part 4 Stainless Steel Spheres</u>

$$V_{outer} = \frac{4}{3}\pi r_{outer}^3$$

r_{outer} is the outer radius of the large stainless steel sphere, calculated in Table 2

$$V_{inner} = \frac{4}{3}\pi r_{inner}^3$$

r_{inner} is the inner radius of the large stainless steel sphere

$$V_{outer} - V_{inner} = \frac{m_{small\ sphere}}{\rho_{stainlesssteel}}$$

volume of stainless steel used to make each stainless steel sphere

IV. Equipment and Materials

Computer, calculator, objects, density samples, electronic balance, graduated cylinder, large beaker for hot water, hot plate, cold water, red, blue or green food coloring, salt, alcohol, 500 mL or 600 mL beaker, 1,000 mL beaker, safflower oil, density rod, ruler, stirring rod, goggles, stainless steel spheres, large bowl

V. Procedure

<u>Part 1 Objects</u>

1. Select 10 objects or items from the density samples.

2. Record their masses in Table 1.

3. Put some water in a graduated cylinder and record the starting volume, which you will use to determine the *total* volume of water displaced by the *submerged* object, needed to calculate the object's density.

4. Gently drop the object into the graduated cylinder. If the object floats push it down with the end of a pen or pencil so that its surface is just below the top of the water. Record the change in volume.

5. Calculate the density of the object from its mass and its *submerged* volume.

6. After recording the object's volume remove the point of the pencil and allow it to float.

7. Determine the volume of the water displaced by the *released* object.

8. The mass in grams of the displaced water is the same as the change in volume caused by the object when it is released and allowed to sink or float. Remember that 1 ml of water = 1 cm^3 of water = 1 gram of water.

9. Calculate the weight of the water displaced by the *released* object. Be sure to use the correct value of *g* from the Newtons and Dynes handout!

<u>Part 2 Density Rod I</u>

10. Partially fill a 500 mL beaker or 600 mL beaker with hot water so that the height of the water is greater than the length of the density rod. Place the density rod next to the beaker to check.

11. Place the density rod in the beaker and record your observations.

12. Empty the hot water out of the beaker into another safe container.
13. Half fill the beaker with cold water then gently pour the hot water from the container that you just put it in on top of the cold water. Again, be sure that the height of the water is greater than the length of the density rod.

14. Insert the density rod in the beaker and record your observations.

15. Empty the water out of the beaker.

16. Partly fill the beaker with room temperature water and insert the density rod. Record your observations.

17. Add a few grams of salt and stir. Record your observations.

18. Next, you will create a mixture that has 10% alcohol and 90% water.

19. Pour out the water and rinse out the beaker.

20. Partially fill the beaker with room temperature water.

21. Divide the number of mL of water by 9. Gently add that number of mL of alcohol to the water.

22. Place the density rod in the beaker. Record your observations.

23. Gently stir the alcohol-water mixture and record your observations.

24. Dispose of the alcohol-water mixture in the designated waste container, **not** down the sink.

<u>Part 3 Density Rod II</u>

25. Measure and record the length L of the density rod in cm. $L =$

26. Put at least 800 mL of water in the 1000 mL beaker, add some food coloring and stir.

27. Insert the density rod in the middle of the beaker.

28. Slowly pour between 100 mL and 200 mL of safflower oil into the 1000 mL beaker and allow the water and oil to separate and settle.

29. Without disturbing the water and the oil, gently move the rod to the side of the beaker. If the density rod is horizontal push on it with a pen or pencil to make it vertical against the side of the beaker, but be sure not to push it upwards or downwards.

30. Measure the height of the part of the rod in the oil. This is the variable x, which you will use to determine the density ρ_r of the density rod. $x =$

31. Dispose of the oil-water mixture in the designated waste container, **NOT** down the sink.

<u>Part 4 Stainless Steel Spheres</u>

32. Determine the mass of each of the two stainless steel spheres and record the results in Table 2.

33. Place the two stainless steel spheres, one at a time, in a large bowl filled with water to a depth greater than the diameter of each sphere. Observe the behavior of the spheres.

34. Complete Table 2.

VI. Data

Table 1 Object Mass, Volume, and Density

A	B	C	D	E	F
Object	Mass m of object in grams	Volume V of object in cm^3	Density ρ of object in $grams/cm^3$	Mass of displaced water in grams	Weight of displaced water $W_{water} = F_B$ in dynes

Table 2 Stainless Steel Sphere Data

A	B	C	D	E	F
Object	Diameter d of stainless steel sphere in cm	Radius r of stainless steel sphere in cm	Mass m of stainless steel sphere in grams	Volume V of stainless steel sphere in cm^3	Density ρ of stainless steel sphere in $grams/cm^3$
small stainless steel sphere	3.49				
large stainless steel sphere (including air inside)	12.7				

VII. Discussion Questions

Part 1 Objects

1. What is the mathematical relationship between the weight of the displaced water, W_{water} and the buoyant force, F_B?

Part 2 Density Rod I

2. What happens to the position of the density rod in the beaker as the water cools? Why? What changes?

3. Does the density rod behave differently in hot water and cold water? Why?

4. How does the density rod behave when the bottom of the beaker contains cold water and the top of the beaker contains hot water?

5. What effect, if any, does salt have on the behavior of the density rod? Why?

6. What effect, if any, does the addition of alcohol have on the behavior of the density rod? Why?

Part 3 Density Rod II

7. What is the density of the oil ρ_o in grams/cm^3? Hint: you will need to look this up and/or convert to these units.

8. What is the equation for calculating the value of the density ρ_r of the density rod?

9. Calculate the density ρ_r of the density rod. Show your calculations. Make sure that your answer is reasonable.

10. The density of the rod must be between what two values? Why? If your answer to the previous question is not between the two correct values you must redo your calculations and obtain a possible, correct answer.

Part 4 Stainless Steel Spheres

11. Explain why the large stainless steel sphere floats and the small stainless steel sphere sinks.

12. Assume that the small sphere is solid stainless steel. What is the density, $\rho_{stainless\ \ steel}$, of stainless steel?

13. How many cm^3 of stainless steel were used to make the spheres? Hint: the answer is the same for both stainless steel spheres, and is equal to the numerical value of $V_{outer} - V_{inner}$ for the large stainless steel sphere.

14. Derive the equation for r_{inner} in terms of the variables r_{outer}, V_{outer}, and V_{inner}. Show the steps, starting with the equations in the Calculations section for Part 4 Stainless Steel Spheres.

15. Calculate the numerical value of r_{inner}.

16. What is the numerical value of r_{outer} - r_{inner}, the thickness of the large stainless steel sphere?

17. Assuming that the outside volume does **not** change, how much mass, in grams, would need to be *removed* from the interior of the small stainless steel sphere so that its density was the same as that of water? Show your calculations.

18. Assuming that the outside volume does **not** change, how much mass, in grams, would need to be *added* to the interior of the large stainless steel sphere so that its density was the same as that of water? Show your calculations.