Density Notes

Density is defined as the mass of a unit volume of a substance. If, for example, you have 1.00 gram of water, it has a volume of 1.00 cm^3. Its density is 1.00 g/cm^3. The proper units would be kg/m^3 but g/cm^3 are frequently used. If 2.0 grams of sulfur has a volume of 1.0 cm^3, the density of sulfur is 2.0 g/cm^3.

Expressed mathematically, density = mass/volume

Solids - The table below which lists the densities of a variety of solids emphasizes that the densities of solids vary over a wide range. A few are less dense than water and thus will float. Others are ten to twenty times as dense as water. The density of ice is 0.92 g/cm^3. When you place ice cubes in a glass of water they float. When they melt, why doesn't the water pour over the rim of the glass?

Liquids - First, with the exception of mercury, the range of densities of liquids is considerably narrower than that of solids. Liquids range from about 3/4's to twice the density of water.

Gases - The table lists the densities of some common gases under similar conditions of temperature and pressure. Notice how different they are compared with solids and liquids. Density may allow us to determine the composition of certain pure substances. Usually other test will also be needed to distinguish between substances with similar densities.

All density values in the following table are units of g/cm^3

SOLIDS		LIQUIDS		GASES	
cork	0.24	gasoline	0.68	hydrogen	0.000 09
mahogany	0.85	octane	0.70	helium	0.00018
paraffin wax	0.9	grain alcohol	0.79	ammonia	0.000 77
ice	0.92	wood alcohol	0.81	CO	0.001 25
balsa wood	0.13	coconut oil	0.93	nitrogen	0.001 26
oak	0.72	water, pure	1.00	air	0.001 3
hard coal	1.4 - 1.8	water, sea	1.03	oxygen	0.001 43
sugar	1.6	glycerin	1.26	CO_2	0.00198
bone	1.6	chloroform	1.73	chlorine	0.003 21
concrete	2.3	mercury	13.6		
glass	2.4 - 2.8				
quartz	2.65				
flint	2.6				
aluminum	2.7				
zinc	7.1				
tin	7.3				
iron	7.9				
brass	8.5				
copper	8.9				
silver	10.5				
lead	11.3				
gold	19.3				
platinum	21.5				

Density Problems

1. In each case give an example of a common object that has:
   a. low density and small volume
   b. low density and large volume
   c. high density and small volume
   d. high density and large volume

2. a) name 2 solids that are less dense than water:

   b) name 2 liquids that are more dense than water:

   c) name 2 gases that are more dense than carbon dioxide:

3. One lead cube has an edge 1 cm long; a second lead cube has an edge 2 cm long:
   a) in what properties are the two cubes different? Which of their properties are the same? Explain your answers.
   b) what is the mass of each cube?

4. Use the tables to answer the following:
   a) you are given equal masses of lead, aluminum, platinum, and brass. a) Arrange these masses in order of increasing volume.
   b) you are given equal volumes of the same metals. Arrange them in order of increasing mass.

5. Under what conditions would it be difficult or impossible to measure the volume of a solid by displacement? Explain.

6. Use the tables to answer the following:
   a) what is the mass of 10.0 m^3 of water
   b) what is the mass of 5 ft^3 of aluminum

7. Calculate the volume of 1 gram of each of the following: balsa wood, aluminum, alcohol, oxygen

8. Calculate the mass of: 10 mL of alcohol, 5 mL of platinum, 10 L of oxygen

Added Notes: Density and Archimedes

King Hieron of Sicily gave a jeweler gold to be formed into a crown. When the crown was delivered it weighed as much as the gold that had been given to the jeweler. The king thought foul play was afoot.

Archimedes was asked to figure out if something had been substituted for part of the gold. When taking a bath Archimedes noted that the volume of his body was equal to the volume of water displaced when he sank into the tub. Also a submerged object lost as much weight as the weight of the water it displaced.

He found the crown to occupy a volume greater than one would expect that much gold to occupy (by looking at the amount of water it displaced) and concluded that it contained some silver as well.

Further notes: **Buoyancy**

1. a heavy object floats if its volume is large enough to displace a volume of water of equal mass.

2. a rock held below the surface of water appears to lose weight due to buoyancy (buoyant force exist because water pressure increases with depth - a diver under water suspended on a cable experiences forces on his body due to water pressure - this diver experiences greater pressure against his feet due to greater water pressure at greater depths than on his head resulting in a net upward force (the buoyant force))

3. If an object weighs less than the buoyant force, it floats. If it weighs more than the buoyant force it sinks. If its weight is equal to the buoyant force it can remain at any level.

4. **The buoyant force on an object is equal to the weight of the liquid it displaces**.

5. A ship weighing 10 000 kg displaces a great deal of water and will float. A cube of steel weighing 10 000 kg will sink (its weight is the same but the cube doesn't displace nearly as much volume as the hull of the ship.

Density of Solids Lab

1. Read the lab guide carefully, plan and prepare your notecard, and review the lab write-up procedures. We will do the write-up together in class. Each member of the lab group should understand the steps before performing the lab.

2. Using normal observation, try to identify each of your samples. For solids with a regular geometric shape use Run 1 procedure, for irregular solids, use Run 2 procedure. For the metal cylinder use both procedures and we can compare your results.

3. You must make all measurements needed first. After all data collection is made you may begin your calculations.

Run 1 - Procedure for regular geometric solids

Thoroughly dry the solid objects. Mass each accurately. Record the measurements needed on your notecard. You will be using rulers and vernier calipers to make the measurements.

Run 2 - Procedure for irregular solids

Dry the objects and mass each separately. Use the graduated cylinder to find the volume of these objects by water displacement. Remember to read the graduated cylinder to the tenths place. Remember to place it on the counter and read the bottom of the meniscus.

Formulas that may be needed:

density = mass/volume

volume of sphere = $4/3\ \pi\ r^3$ $\pi = 3.1416$

volume of cylinder = $\pi\ r^2\ L$

radius of sphere = circumference/2π or diameter/2

volume of rectangle = length x width x height

% difference = | difference of two densities / larger of two densities | x 100 = ____%

Questions to be answered in lab write-up:

1. How would you find the density of an irregular shaped object that would not fit in any graduated cylinder?

2. How would air bubbles sticking to an object affect your volume measurement?

3. Devise a method for obtaining the volume of a teaspoonful of sugar crystals, remembering that sugar will dissolve in water.

4. A submarine rises and sinks by changing its density. If the density changes, its mass or volume or both must change. Explain how a submarine rises and sinks using density.

5. The density of ice is 0.92 g/cm^3. The mass of a block of ice is 2.0 kg. What is its volume? Show your work here. How does the ice have a density lower than that of water itself?

6. How do you measure the volume of an object that floats?

7. Try to explain density on an atomic or molecular level.

RELATIONSHIPS BETWEEN VARIABLES: MASS AND VOLUME OF A LIQUID

Objectives:

1. To determine the relationship which exists between the mass and volume of a liquid.
2. To find a mathematical expression for the relationship.
3. To use the relationship for prediction.
4. To practice making graphs.

Introduction:

The study of a particular phenomenon often suggests that two measured properties are related to each other. An experiment can then be designed to determine this relationship by measuring the effect that changing one property (the independent variable) has on the other (the dependent variable). In this experiment we will study the way the mass and the volume of a liquid are related.

In searching for relationships between two properties it is frequently useful to make a graph showing how one property varies with the other. Each of the coordinates on the graph represents one of the properties being studied. In an experiment involved with mass and volume we might have the volume values along the x-axis (the bottom) and the mass values along the y-axis (vertical). To make the graph we would put data points for each sample at the proper values of volume and mass. If, for example, we find that a sample containing 2.0 cm^3 and mass equals 2.80 grams. By using all the data points we get an idea of how the mass varies with volume. In order to be able to say what the mass of the sample would be for volumes other than those we measured, we draw a line through the data points which best fits the trend shown by those points. Having found the line showing how the properties like mass and volume are related, it is often possible to find a mathematical equation for that line. That equation can then be used to calculate one property when the other one is known. In this experiment we will be doing all of these things, with the ultimate purpose of understanding that property of a liquid called its density.

Our actual experiment is quite simple. We will measure the volume and mass of several different liquid samples, working first with water and then with an unknown liquid. These measurements will furnish us with the data from which we can make and interpret graphs for the mass volume relationships of water and the unknown.

Procedure:

1. Mass a clean, dry graduated cylinder to the nearest 0.1 grams.
2. Add water until the level is as close as possible to the 10 mL mark. Read the level and mass again. Make the volume measurement at the bottom of the liquid meniscus.
3. Add another 10 mL of water. Read the volume and mass the cylinder again. Continue in this way to make the volume and mass measurements for every 10 mL up to 50 mL mark. Record all volumes to the nearest 0.1 mL and all masses to the nearest 0.1 gram.
4. Empty and dry the graduated cylinder. Repeat procedure steps 2 and 3 with the unknown liquid. Record your values for the unknown liquid.

Sample Data Table

Mass of graduated cylinder = ___________ g

Total volume of water	Mass of grad.cyl. and water	Total mass of water
____________________ mL	______________ g	_____________g
____________________	______________	_____________
____________________	______________	_____________
____________________	______________	_____________
____________________	______________	_____________

Use a similar arrangement for the data on the unknown liquid.

CALCULATIONS AND QUESTIONS

1. From the data obtained, calculate the total mass of the water in the cylinder for each of the volumes you measured. Carry out similar calculations for the mass of the unknown liquid for each volume.

2. On graph paper plot the data you obtained for the water samples. Plot mass on the y-axis and volume on the x-axis. You should have a point on the graph paper showing the volume and mass for each sample you measured. When you have completed plotting the data, draw a straight line through the data points in such a way as to minimize the distances the points lie off the line. Your line should go through the origin (why?). Repeat the procedure, plotting the data you found for the unknown liquid, and drawing a line through those data points. Label the first line as WATER, and the other line as UNKNOWN LIQUID.

3. The lines on the graph describe how the volume and mass of each of the two liquids are related. For any given volume, we can find the mass that volume of water, or unknown liquid, would have. Using the line for water on the graph, find the mass of water which

would have the following volumes: 5 mL, 15 mL, 25 mL, 35 mL. Then using the line for the unknown, find the mass of the unknown liquid which would have each of these volumes.

4. This method works for certain values of the volume, but what about 14.3 mL or 76 mL. At this point I will show you how to find the density of the liquids from our graph using the slope of the line you drew. This will then allow you to find any values needed if this constant (density for that substance) is known or found as you have in this lab.

Pencil Density Exploration

Given: density of graphite core material = 1.46 g/cm^3

Problem: Find the density of the pencil if the core material was removed (i.e. what is the density of the wood excluding the graphite core):

Instructions: Show all work beneath the individual question. Record final answers to at least 3 sig figs.

Final Answer: ________________________

Mass of full pencil (with core): ____________________

Length of pencil (same as core length): __________________

Diameter of pencil: ______________________

Diameter of graphite core: ______________________

Volume of pencil (full): _______________________

Density of pencil (full, with core): __________________

Mass of graphite core: _____________________

Volume of graphite core: _____________________

Density of graphite core material: ___________________

Mass of pencil without core: ____________________

Volume of pencil without core: ______________________

Balloon Wars

Step 1: Calculate area density

a) find mass of paper __________g

b) find area of paper __________cm^2

c) divide mass by area __________g/cm^2

Step 2: Calculate net upward force

a) place mass on scales, record: ____________g

b) attach balloons, record new mass ___________g

c) subtract two reading (NUF): __________g

Step 3: Calculate area of material needed

a) if NUF should equal 15 grams (this means that if the balloon is attached to an object of 15 grams it should be able to lift it off the ground but not rise)

b) pick a safety margin (example: 2 %) if balloon can lift 15 grams we take 2 % of 15 grams (0.3 grams) and subtract from 15 g to get target lift mass of 14.7 grams

c) to find area of material needed (cm^2) we must the the density formula: (hint: we just found mass needed and we calculated the area density earlier):

$$\text{area needed} = \frac{\text{target lift mass}}{\text{area density}}$$

d) find dimensions (must be perfectly square) of paper needed: (hint area = $side^2$ - square root of area needed gives length of each side)

e) teacher can check for square by checking diagonals - they should be equal)

Step 4: Test Flight

a) attach balloon to target paper at floor level and use stop watch to time ascent to ceiling

b) find area to test that has no strong drafts.

The Hot Air Balloon

For drawings see Mr. Jones

Purpose: to explain the relationship of density and Archimedes' Principle to the flight of a hot air balloon.

Background: Archimedes' Principle states that a body immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced. In other words, a body immersed in a fluid seems to lose weight equal in amount to the weight of the fluid displaced. This is the result of the upward pressure of the fluid. Archimedes' Principle helps us to understand why objects that have a density greater than that of water will sink while those with a density less than 1.00 g/cm^3 will float. Air is fluid; therefore, we can apply the principle to objects immersed in it. As air is heated, it expands, causing its density to decrease. The heated air will float upward in the more dense cooler body of air for the same reason a cork will float to the surface of water.

Materials: 24 sheets of tissue wrapping paper, string, scissors, glue sticks, wire ring, paper clips

Procedure:

1. Each of the 8 gores is made of 3 sheets of tissue paper, glued end to end. Place sheet 1 over sheet 2 allowing the bottom sheet to extend 1 cm outward. Place glue on this extension, fold up and over the top sheet. Repeat with sheet 3, gluing it to sheet 2. Unfold, allow to dry, and repeat 7 more times. (8 x 3 = 24 sheets - arranging for color if you wish).

2. Stack all 8 dry gores on top of teach other and cut out a cigar pattern, to a sharp point at the top and a wider (10-12 cm) opening at bottom. Cut all 8 gores to this same shape. Just about any shape will do.

3. The gores will be glued together in a similar fashion to the earlier gores. Lay sheet 1 on top of sheet 2. Allow 1 cm of bottom sheet to extend outward. Place glue here and fold up and over. **Now a key point. Place sheet 3 on top of sheet 2. You must glue sheet 2 up and over sheet 3 but on the opposite side.** As you continue you will be creating an accordion of sorts. You must glue on alternate sides as you add gores.

4. Finally glue the last two ends (free) together. Tie all 8 gores together with string at the top (twist into an air tight knot and tie a loop around it.) This loop will be used to hang balloon.

5. At the bottom you must fold, glue, staple, etc. all the bottom into a opening about 10-12 cm across. This is difficult. Then inflate your balloon with a hair dryer and check for leaks or tears. These can be repaired easily. **Be careful not to use flames to check. This balloon is extremely flammable.**

6. Bring the balloon to school for a test flight. You can complete part 2 at home or at school.

Part 2 Calculating Lift Capability

Purpose: To calculate the lift capability of your balloon.

Materials: metric ruler or meter stick, lab scales

Procedure: 1. A cubic meter of air has a mass of about 1.0 kg. this means that a massless bubble can lift about 1.0 kg for each cubic meter of volume. The hot air pumped into your balloon displaces the cooler more dense air, creating a buoyant lifting force. By calculating the volume of the balloon you can determine the force of buoyancy.

Density = mass/volume or Buoyant Force (mass) = density of balloon x density of air

If you balloon is assumed to be a sphere , then our formula becomes:

buoyant Force = $4/3\ \pi\ r^3 \times 1.00\ kg/m^3$ (r is the radius)

2. Determine the radius of your balloon. Radius = ___________cm or __________m

3. Calculate the buoyant force of your balloon using the formula in step 1 above. Show your math work.

Buoyant Force = ________________kg

4. You hot air balloon, however, is not massless. The paper, glue, wire and even the air have mass. To determine the actual payload which your balloon can lift, you must take into account these masses. By subtracting these from the buoyancy lift force, you can determine if and by how much your balloon will become airborne.

Determine the mass (kg) of your balloon. Mass = ___________________kg

5. Now let's determine the mass of the hot air. Since you already know the volume of the air in the balloon, you can multiply that by the density of air to get the mass of the air. Heated air has less density, and therefore, less mass. Multiply the volume of your balloon by the density value given below (this number is an estimate and may need to be changed) to obtain the mass of the air.

Assuming a mid-range temperature of 100 ° C, the density of the hot air would be $0.75\ kg/m^3$

mass of hot air = $4/3\ \pi\ r^3 \times 0.75\ kg/m^3$ = _____________kg

6. Now you are ready to determine the payload of your balloon using this formula:

PAYLOAD = Buoyant Force (step 3) - Mass of Balloon (step 4) - Mass of hot air (step 5)

What is the payload of your balloon? ______________kg

Will it lift off? _________________(if your payload value is a positive number or exceeds 0.01 kg, the balloon will lift.)

Further calculations:

1. Calculate the payload of a balloon that has a radius of 2.0 m and a mass of 0.15 kg. The hot air density is 0.50 kg/m^3.

2. Helium gas has $1/7^{th}$ the density of air at the same temperature. Calculate the payload of the balloon in question 1 (above) if the balloon were filled with helium.

Conclusions: With a hot air balloon, the hotter the air, the ___________________(greater or lesser)

Use the following chart of temperatures to determine the corresponding density of heated air.

Temp °C	20	50	75	100	125	150	200	250	300
Density kg/m^3	1.00	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50