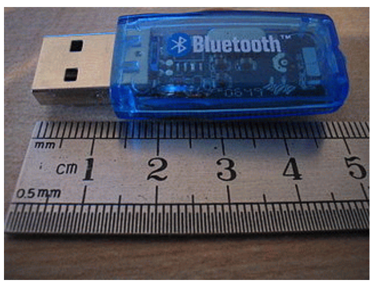
Water,  **Density** 

and 

 **Metrics** 

An Interactive Hands-on Science Exhibit

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Water, Density and Metrics Exhibit

This web site has been designed to provide instructions, templates and materials needed for the design and implementation of an interactive science exhibit titled ***Water, Density and Metrics***. The exhibit consists of several sections of activities that include observations, questions and measurements. Most of the explorations are related to the physical property called density (the ratio of mass to volume). Topics covered include the unusual behavior of the density of water as a function of temperature and additional concepts that are important in our lives such as measurement systems and climate change. Hands-on activities are often included that have been selected based on instructional value, safety, ease of implementation and cost. The equipment for the basic sections of the exhibit can be purchased for the total cost of a few hundred dollars. The exhibit provides a learning environment for people of all ages. While a few of the concepts might be beyond the capabilities of some elementary school children, the children should be able to make some meaningful observations. The exhibit will hopefully turn people on to science as it demonstrates the importance, excitement and fun associated with scientific investigations.

The exhibit was used by the Stanislaus County Office of Education at the SCOE booth at the Stanislaus County Fair in 2009. Although successful and enjoyed by many visitors to the Fair, the venue was not ideal as people at fairs do not spend sufficient time at each booth to gain full benefit of the learning experience. The exhibit should be more appropriate for a museum type of environment where visitors often dwell for a significant amount of time at any exhibit that draws their attention.

Instructions for Exhibit

A binder with the templates included should be provided. Alternatively, individual section templates can be placed near the additional items needed (if any) for each section. There are also templates for smaller card size attachments that should be attached or near the items used for each section.

1. This section deals with some of the properties of water. Three questions about the percentage of water in a human body, the color of water and the size of a water molecule are included to initiate the investigation into the properties of water. Template 1 contains the questions and images that help elucidate the concepts. Template 1A contains the answers and a bonus question that continues to develop the concept of molecular size. The primary emphasis is on the importance of accuracy when communicating (clear or transparent are not correct answers to the question; what color is water) and to impress on people how small a water molecule is (by finding out that you drink 6 septillion molecules when you drink a glass of water).

2. This section focuses on measurements and the advantages of the metric system over the U.S. customary system.

2-1, 2. The first activity in this section is intended to demonstrate that use of the hand is not necessarily a good way to estimate weight. People should estimate the weight (we will not distinguish between weight and mass even though there is a technical and significant difference) of the 3 objects (rank them on the handout sheet) and then weigh them. Usually, most people rank the ball bearing as heaviest even though it is the lightest. The brain senses the pressure of the object (mass divided by area) rather than mass alone. This brings into question the use of the hand in grocery stores to compare mass although it is probably ok as long as the objects are the same size.

2-3,5. These questions are included to demonstrate that the metric system is far superior to the U.S. customary system. ***Question 3*** below and its answers summarize the reasons.

2-4. The hydrometer is a simple instrument for measuring density. Since density is the ratio of the mass to the volume, density determinations require measurements of both mass and volume. However, the hydrometer is a calibrated device that directly reads out density (actually it reads out specific gravity but this exhibit will not distinguish between specific gravity and density). If read correctly, the density should be read as very slightly less than 1 g/mL.

2-Bonus Exercise. Several companies sell kits of density cubes (most are 1 cubic inch but Sempco does have 1 cm^3 cubes. The problem with the latter is that the mass of each cube is low and it might be difficult to distinguish small differences. Edmund Scientific has the lowest priced kits but Delta-education, Wards, Frey's and NASCO also have kits.

3. This section puts together the observations of question 2. It deals with the advantages of the metric system and involves reading of the binder material.

4. For section 4, the image on the first page is very important. The picture shows 6 test tubes, each containing the solid and liquid phases of a single substance. Many people will assume that each tube contains the liquid of a substance and frozen water (ice) but this is not the case. Stress that each test tube contains only one substance and the only one with water is the third one from the left. Because almost everyone has only seen the solid and liquid phases of water together, they assume that the solid of a substance will float in its liquid. However, except for water and a very small number of other substances, the solids as should be expected are denser than the liquids and sink as demostrated in the photo. Page 4B in the binder attempts to give a reason for the very unusual behavior of water. Without getting too technical, the molecules in liquid water are closer together than they are in the solid. The reason for this is the same reason that DNA is a double helix - hydrogen bonding.

5. This section deals with the relative densities of liquids and the miscibility of liquids.

5-1. The test tube rack contains 6 different pairs of immiscible liquids (liquids that are not soluble in each other such as oil and water). The denser of the two liquids is on the bottom. A seventh test tube contains all seven liquids. While mixing of the tubes with two liquids (ther first 6), do not allow mixing of the 7th tube (multilayer tube) as some of the layers are miscible with each other but are separated by another immiscible liquid. Shaking would cause some of the layers to mix and merge decreasing the number of layers. By using logic from the observation of the 6 test tubes, it should easily be possible to determine the order of the liquids in the 7 layer tube.

Six test tubes containing immiscible liquids as indicated in 5-1. 7th tube is not pictured and the number of layers in the 7 liquid layer will eventually decrease.

5-2. Participants should turn on the stirrer and can change the stirring rate to mix the two immisible liquids in the jar (the top layer is mineral oil colored with a tiny amount of iodine and the bottom layer is water colored with food coloring). They should note that the layers separate again when the stirring is stopped. The question is what is causing the spinning action and page 5A shows that the box contains a motor that spins a magnet and that there is a magnet in the solution.

6. This section deals with observations and activities that illustrate the importance of density.

Regular and caffeine free diet coke. Pepsi's not pictured.

6-1. The large plastic file cabinet or garbage can is filled with water and contains cans of Pepsi, diet-Pepsi, Coca Cola and diet Coca Cola. Observers should ask why the diets float and the regulars sink. The regulars are denser because of the sugar in the drinks. Artificial sweeteners are about 200 times sweeter than sugar and only small amounts are needed thus the diet drinks have less mass and have lower density than the regular drinks.

6-2. Although the masses of the two pieces of aluminum are the same, the densities of the objects are much different as the floating one contains a considerable amount of air.

6-3. Challenge the spectators to make a float out of the aluminum that will hold the highest number of pennies. The boat will sink when its density (mass divided by total volume exceeds the density of water or 1 g/mL). Thus the objective is to make the volume as large as possible. <u>The aluminum foil needs to be cut into 3 inch square sheets.</u>

N_2, air, O_2 but CO_2 not pictured as bottle collapsed after several months.

7. This section uses mass measurements to probe some of the issues involved in climate change. Before starting, participants should say what they think are the three most abundant gases in dry air (water varies and is sometimes #3). The 2 qt bottles contain air, oxygen, nitrogen and carbon dioxide. The sheet with places for writing in answers for the masses in sections 2-1, 2 should also have a blanks for writing down the air contents and measured bottle weights. The weight of each tightly capped empty bottle (without air) was carefully adjusted by the addition of 15 g of weights and removal of small amounts of label to be 100.00 g (actually the mass of each bottle with air was adjusted to 102.24 g). Thus the mass over 100.00 g is the mass of the gas in the bottle. It should come out about 2.17 g for nitrogen, 2.24 g for air, 2.48 g for oxygen (close to the mass of a penny - about 2.5 g) and 3.41 g for carbon dioxide . Since the weight for air is close to the weight for nitrogen, people should be able to conclude that there cannot be much carbon dioxide in the air or the bottle would weigh more. In fact the air is about 78% nitrogen and 21% oxygen which is consistent with the weight of the air bottle. Almost no one will have named argon as the number 3 gas and many will name carbon dioxide as one of the top 3 (some name it as number 1). Because there is little carbon dioxide in the atmosphere, the human activity of fossil fuel burning has raised the carbon dioxide content of the atmosphere from 0.0280% to 0.0388% and it will continue to increase if we continue to burn fossil fuels. Most scientists think this increase has already had a significant effect on global climates and if solutions are not implemented soon, disastrous climatic changes could be the result. A final note is that it is interesting that the mass of 2 qts of gas is close to the mass of a penny despite the huge difference in volume. This illustrates that gases are about a thousand or more times less dense than liquids and solids.

8. This section includes additional questions primarily related to density and mass measurements that are intended to increase interest and demonstrate the importance of measurement and scientific concepts. The exhibit can include as many of these questions as desired. Two questions on light refraction and velcro were included because of the ease of setting them up, the fascination of the exhibits and especially for the velcro, the problem is solvable by observation.

8-1. The egg has a density slightly greater than the density of water and sinks in water but the bottom liquid (diethylphthalate) is denser than the egg and the egg floats in it and ends up suspended between the two liquids. The egg will eventually dissolve and have to be replaced.

8-2. The Galileo thermometer functions as a result of density changes with temperature. As the temperature increases the density of the liquid decreases and more of the objects whose density is essentially independent of temperature become denser than the liquid and sink. A thermometer with a wire cage is recommended to minimize the chance of breakage.

8-3. The masses of pre- and post- 1982 pennies are compared. Pre-1982 pennies were made out of copper (density = 8.92 g/cm^3). Because of the high cost of copper, post-1982 pennies were made out of zinc (density = 7.14 g/cm^3) and copper coated. Since the volumes (0.35 cm^3) of the pennies are the same, the zinc pennies (2.53 g) weigh about 20% less than the copper ones (3.12 g).

8-4. The question here deals with the floating and sinking of balloons. Just like the sinking or floating of objects in water is determined by the densities of the object and water, the sinking or floating of objects in air is determined by the densities of the object and air.

8-5. The question posed here is whether a bowling ball will sink or float in water? A bowling ball has a maximum mass of 16 lbs and a diameter of 8.594 inches or a radius of 10.914 cm. The volume is $4/3\pi r^3$ or 5446 cm^3. The ball will have a density of 0.998 g/cm^3 at 20^{o}C if it has a mass of 5435 g or 12.0 lbs (5435 g/5446 cm^3 = 0.998 g/cm^3). Bowling balls weighing more than 12 lbs should sink and those weighing less than 12 lbs should float.

8-6. This question points illustrates the fact that titanium is very useful because of its high strength but low density.

8-7. The bottom half of a test tube is barely visible in the liquid because the liquid (either glycerol or Wesson oil should work) bends (refracts) light the same amount as glass. Water and glass refract light different amounts thus glass in water is easily observable.

8-8. Careful examination of the Velcro with the magnifying lens reveals that the Velcro has catches on one piece and hooks on the other.

8-9. Careful observation reveals that ABCDEFGHIJKLMNOPQSTUVWXYZ is not the alphabet as it is missing a R. The letters are a chemical pun for argon as the R is gone.

8-10. This interactive exhibit is probably the most interesting of all but should only be included if continual supervision and maintenance is possible. As it uses dry ice, it must continually be maintained and will have a significant maintenance supply budget as dry ice will have to be added frequently. Bubbles are blown by visitors or the exhibit supervisor so that the bubbles descend into an aquarium containing dry ice. The bubbles will float on the layer of carbon dioxide as CO_2 is denser than the bubbles. Dry ice must be replenished or the carbon dioxide layer will mix with the air and the bubbles will no longer float.

Materials needed for each section:

1. Templates 1, 1A, 1B
   Molecular model of water.

2. Templates 2, 2A
   Three objects preferably in a plastic bucket: rubber stopper (#8, 28 g), ball bearing (11/16" diameter, 21.6 g), huge cork or small cork ring 34 g). A blackboard eraser can be substituted for the cork.
   Balance 200 g capacity, 0.01 g readability. *My Weigh* i201 - $118 at: http://www.oldwillknottscales.com/my-weigh-ibalance-201.html (will be used again in a later section)
   1 gallon plastic milk bottle, 1 foot ruler
   Hydrometer (Amazon has a huge selection - for precision try H-B 50415 or 50565 with a range of 0.94 - 1.01 or for broad range, H-B 50885 with a range of 0.7 - 2. Prices are close to $20.

3. Templates 3, 3A

4. Templates 4, 4A, 4B (The image in 4 is extremely important for this exhibit)
   Good images of liquid water and ice are on the Internet at:
   http://www.nyu.edu/pages/mathmol/library/water/water_box.gif
   http://www.nyu.edu/pages/mathmol/modules/water/hbond_ice.gif
   http://www.nyu.edu/pages/mathmol/modules/water/wat_10A.gif
   http://www.nyu.edu/pages/mathmol/modules/water/ice_10A.gif

5. 7 sealed tubes (preferably vials with screwed on tops with tape preventing removal of the top).

tube 1	dodecane, ethanol
tube 2	ethanol, mineral oil
tube 3	mineral oil, water
tube 4	water, oil of wintergreen (methyl salicylate)
tube 5	oil of wintergreen, salt water (saturated - 26%)
tube 6	salt water, FC-70
tube 7	dodecane, ethanol, mineral oil, water, wintergreen oil (methyl salicylate), salt water (saturated - 26%), FC-70 (perfluorotripentylamine)

   magnetic stirring device, teflon coated stirring bar, sealed plastic bottle (0.5 L) containing 100 mL of mineral oil (with trace of iodine) and 100 mL of water (with a couple of drops of green food coloring)

6. Clear kitchen size plastic garbage can with top about 2/3 full of water.
   12 oz soda cans of Pepsi, diet Pepsi, Coca Cola and diet Coca Cola or similar.
   Metal or plastic cake size pan about ½ full of water.
   Many 3 inch squares of aluminum foil with one piece loosely wadded and another folded tightly.
   50 pennies

7. Four 2 qt plastic juice bottles (V8 Splash 2 qt bottles weigh about 85 g)
The bottles should be purged with and filled with nitrogen, oxygen, carbon dioxide and air, all tightly capped. The carbon dioxide bottle lasted a few months and then collapsed.
Balance (see # 2 above)

8. A raw egg suspended in a sealed bottle between diethylphthalate and water.
A Galileo thermometer, 60^{o} - 100^{o} F range with 11 floats for 4^{o} intervals. Wire cage to provide protection from breakage. (e.g., GWS-YG641 from http://www.brassbinnacle.com/ or http://thermometergalileo.cheapdgx530.com/

Two U.S. cents, one pre 1982 and one post 1982
optional - a mylar balloon
2 large tubs half full of water and 2 bowling balls, one under 12 lbs and the other over 12 lbs.
2 sealed bottles: one with water and a test tube and one with glycerol and a test tube.
samples of velcro and a strong magnifying glass (or a magnifying video camera with a projector and screen).
An aquarium or similar tank with clear colorless walls.
Dry ice.
Supply of bubble soap and wand.

1

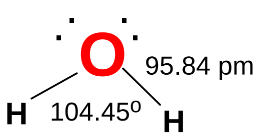
This exhibit has been designed to improve your knowledge about the properties of water, a compound vitally important for life.

1. **Do you know the percentage of water in your body?**

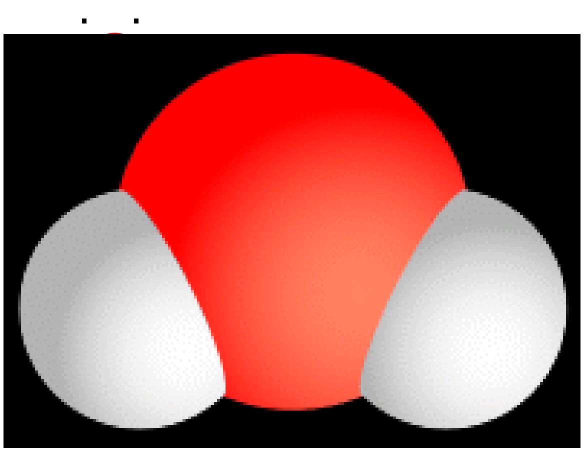
2. **What color is water?**

3. Size of the water molecule. A model of molecule of water is hanging from the ring stand. Notice that the molecule is bent. This is very important as it is the reason water is polar. If water were linear, it would not dissolve compounds like sodium chloride and life forms if they could exist would be extremely different. The model is about 1 billion times bigger than an actual water molecule.

When you drink a glass (180 mL or 6 oz.) of water, how many molecules of water do you think you swallow?



$= 9.6\text{x}10^{-11}$ m
$= 3.8\text{x}10^{-9}$ inches
= teeny, tiny!!



1A

1. People are about 70% water so people are walking puddles or big drips.

2. If you said clear or transparent, you did not answer the question. Communication is very important in science and the correct answer for the color of water is **colorless**. The answer "white" is apparently acceptable as one of the definitions of white is "free of color" as in white wine. However, white is usually interpreted by chemists to mean that all the light is reflected and white therefore should be applied to solids and not liquids.

3. The answer is 6 septillion (6×10^{24}) molecules of water or

6,000,000,000,000,000,000,000,000

molecules of water or in chemistry-speak about 10 moles of water.

Bonus Questions

1. If you had 10 moles (6×10^{24} molecules) of marshmallows, could you cover the 48 contiguous states of the U.S. with them?

2. What is HIJKLMNO?

1B

Bonus Question Answers:

1. You should have first asked if the question meant the whimpy toothpick sized marshmallows, regular size marshmallows or the huge campfire size. The answer that follows is based on regular size marshmallows. A mole of marshmallows would cover the U.S. to a depth of about 6000 miles or the whole earth to a depth of 120 miles.

2. HIJKLMNO contains the letters H to O. This is a chemical pun for H_2O

Mass in the metric system. There are 3 objects (cork ring, rubber stopper, ball bearing) in the plastic bucket.

1. **Pick each one of the objects up and rank them from lowest mass to highest mass. A form is available for you to record your rankings. Now weigh each object on the centigram balance.** While weighing, try to get a sense of the magnitude of a gram (about 1/28th of an oz). One gram is a relatively small amount compared to amounts we are used to weighing. Because of this, the balance is considerably more sensitive than balances you have used before. Since the balance has a capacity of less than 0.5 lb, do not place anything heavy on the balance and treat it with care.

2. **Did your estimated rankings agree with the rankings that result from the weighing results? If not, suggest a reason for this discrepant event.**

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Volume in measurement systems. Since distance cubed is a volume measurement, it is convenient when there is an easy relationship in the measurement system between distance cubed and volume. The ball bearing has a volume of **2.79 cm^3 or 2.79 mL** since cm^3 and mL are exactly the same. Since a liter is slightly larger than a quart, the 2 qt plastic bottles that you will weigh later hold 1.89 L and also 1890 mL and 1890 cm^3. The conversion from distance cubed to volume in the metric system is simple.

3. **Can you even approximately estimate how many gallons are in a cubic foot?**

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Density in measurement systems. The density of an object is its mass divided by its volume. Density is independent of the amount and is a useful property for identifying a substance. As you shall see later, density is also the property that determines whether an object will sink or float.

4. **What is the density of water in the metric system? Read the hydrometer in the tall glass cylinder to measure the value.**

5. **What is the density of water in the U.S. customary system?**

Bonus Exercise

In questions 1 and 2 above, you probably found that using your hand to rank relative weights did not work very well. The discrepancy was due primarily to a psychological factor and a size issue. You expected the ball bearing to weigh more and this influenced the interpretation of your observations. When making observations, we need to strive for unbiased, careful and complete results. Even more important for the exercise, your observation was based on the sense of weight as it was distributed in your hand. In other words, you were probably sensing pressure (mass/area) rather than simply mass because each object had a different shape. The ball bearing had only a small area in contact with your hand and the resulting pressure was high. The cork although heavier was in contact with a much larger area of the hand resulting in the sense of a lower pressure. To use your hand as a reliable means of ranking relative masses, the objects must all have the same contact area with your hand. This can be accomplished if the objects are put in to a container such as a large bottle cap which is then held in the hand. Alternatively, a string could be attached to each object and relative masses ranked when the object is held by the string. For this exercise, several objects that have the same dimensions will be ranked according to increasing mass by picking them up. In addition to ranking their masses, suggest how their densities would rank.

2A

1, 2. Mass in the metric system. Almost all people rank the ball bearing as the heaviest object even though it is the lightest of the three objects. Part of the reason for the error in estimation is probably psychological as the ball bearing is expected to be heavier. The main reason for the error is that using your hand to estimate the mass results in a measure of the pressure (mass/area) the object exerts on your hand rather than the mass. For more information, refer to the ***Bonus Exercise*** immediately above.

3. Volume in measurement systems. Most people estimate that there are about 3 gallons per cubic foot but there are actually **7.48 gallons in a cubic foot**. It seems that people are not very good at estimating volumes. Perhaps this is because vision is really a 2 dimensional instrument. Not only do very few people know the number or estimate it correctly, 7.48 ga/ft^3 is an inconvenient number that is difficult to remember. In the metric system, a cube 0.1 m on each side is exactly 1 Liter and for water weighs very close to 1 kg. This means that 1 mL is exactly 1 cm^3 and for water this quantity weighs very close to 1 g. Notice, this exhibit does not even bother to ask you to give the weight of a cubic foot of water (62.4 lbs).

4, 5. The metric system was set up so that the density of water is exactly 1 g/cm^3 at the temperature of its maximum density (3.98^{o}C). Since room temperature is substantially higher than 3.98^{o}C (read the Galileo thermometer to determine the room temperature), the hydrometer should read very slightly below 1.00 g/cm^3. However, even at room temperature, the density of water is within 0.2% of unity. In the U.S. system, it is sometimes said that “a pint is a pound the world around” but there is a 4% error in this saying.

Bonus Exercise Comments. Since the cubes all have the same volume and density is mass/volume, the rankings of mass and density should be the same. Depending on the cubes available, you can check the ranking of some of the cubes by referring to the table in Section 8, question 6

Advantages of the metric system. If you have been reading carefully, you have already noticed several advantages of the metric system over the U. S. customary system used in the United States.

Can you name 6 advantages of the metric system compared to the U. S. customary system?

3A

1. In the U. S. customary system, units are related by factors of 3, 12, 16, 5280 and other ratios that make conversions difficult to perform without a calculator. In the metric system all conversions involve powers of 10 and can be performed in your head.

2. As noted above, the metric system has an exact relationship between distance cubed and volume. In the U. S. customary system, most people cannot even relate distance cubed to volume and the conversion requires several multiplications that generally involve going from the US. customary system to the metric system and back again.

3. For water, the relationship between mass and volume is close to unity at commonly encountered temperatures but in the U. S. customary system, there is a 4% error (a pint is a pound is 4% off) if a unity relationship is assumed.

4. Most of the world uses the metric system and it would be much more convenient and less expensive if only one set of tools could be used internationally.

5. Less important but still significant is the common practice of using mixed units in the U. S. customary system. A baby is said to weigh 7 lbs 6 oz instead of the much easier 3.34 kg. We could say 7.38 lbs but for some reason we don't.

6. Some abbreviations in the U. S. customary system do not make much sense. For example, the relationship between lbs and oz and their parent words is a stretch.

<u>Densities of the liquid and solid of the same substance.</u> Pictured below are test tubes containing only one substance in each tube. The substances were selected because it was possible to easily have both the liquid and solid of each substance coexist in each tube while the picture was taken.

acetophenone	dioxane	water	*p*-xylene	acetic acid	oleic acid
20^0C	12^0C	0^0C	14^0C	17^0C	14^0C

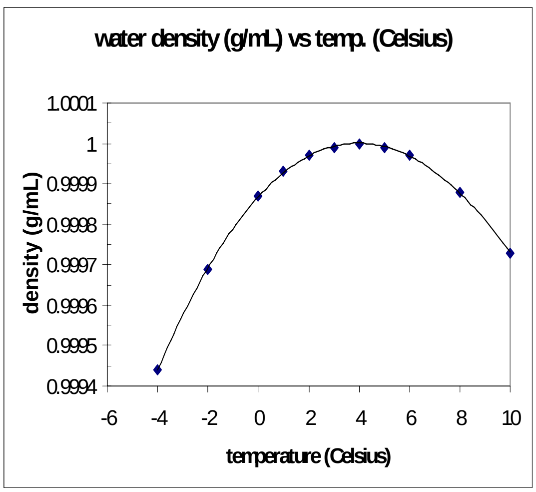
The temperatures are the melting points of each substance and also the temperature at which the liquid and solid of the substance can coexist.

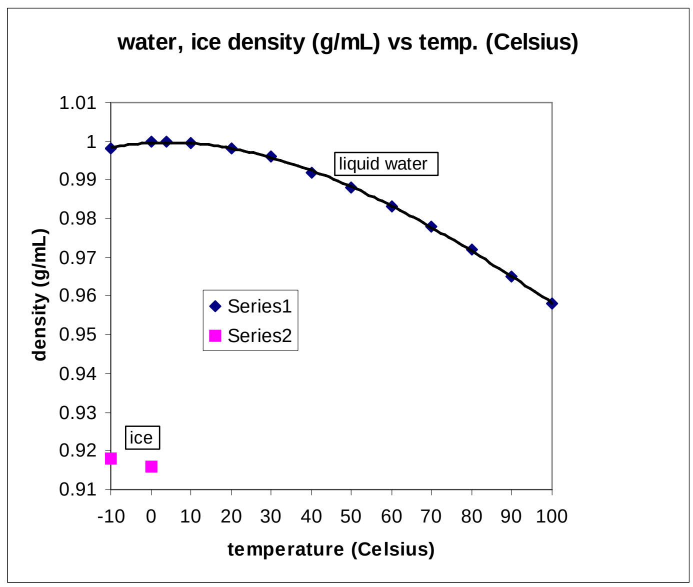
1. **Which substance above exhibits an unusual density relationship between the solid and liquid of the substance?**

2. **Can you name any substance besides water where you have seen the solid and liquid of the substance in a container and you could tell if the solid would sink or float?**

4A

1, 2. This is probably the first experience you have ever had observing the solid and liquid of any other substance besides water. Because you have probably only observed this phenomenon for water, you probably have accepted as "normal" the fact that ice floats on liquid water. However, think about it. As you cool a liquid to the temperature at which freezing occurs, shouldn't contraction take place leading to a higher density with the result that the solid should be denser than the liquid and sink? Actually, for almost all substances except water, this is exactly what happens as you can see above and the solid does sink. The expansion of water when it freezes is a very abnormal and rare behavior. However, we are very lucky that this happens. **If water behaved normally upon freezing, what would happen to lakes and the life in them in the winter?** When the temperature above the lake falls below freezing, the surface of the lake would freeze and the ice would sink. This process would keep repeating itself until the lake fills with ice and life could not exist in lakes in cold climates.





4B

The question why ice floats in liquid water (why ice is less dense than liquid water) is a difficult one but inspection of the images at the sites below reveals that water molecules are closer together in the liquid state than in the solid state.
http://www.nyu.edu/pages/mathmol/library/water/water_box.gif
http://www.nyu.edu/pages/mathmol/modules/water/hbond_ice.gif
http://www.nyu.edu/pages/mathmol/modules/water/wat_10A.gif
http://www.nyu.edu/pages/mathmol/modules/water/ice_10A.gif

Immiscible liquids. As you are aware from your experience in shaking salad dressings, vinegar and oil (vinegar is 95% water and 5 % acetic acid), do not mix. On the other hand, ethanol (ethyl alcohol) and water mix in any proportions. Generally, chemists say that “like dissolves like” and substances of dissimilar polarities often are not soluble in each other. Examine the test tubes in the test tube rack and notice that each tube contains two immiscible liquids.

dodecane	ethanol	mineral oil	water	wintergreen oil	salt water
ethanol	mineral oil	water	wintergreen oil	salt water	FC-70

In the second test tube rack, there is a test tube that contains the 7 liquids that are in the first 6 test tubes.

1. **Based on your observations for the six tubes, determine the order of the layers in the tube containing 7 liquids.** DO NOT TOUCH THE TUBE OR SHAKE IT. ALTHOUGH LAYERS TOUCHING EACH OTHER ARE IMMISCIBLE, SOME OF THE SUBSTANCES ARE EITHER PARTIALLY OR COMPLETELY MISCIBLE AND A DISTURBANCE OF THE TUBE WILL RESULT IN A DECREASE IN THE NUMBER OF LAYERS.

2. The stirring device has 2 immiscible liquids in the container. Turn the knob to start or change the stirring rate and then turn the stirring off. Each of the layers has a small amount of additive to color the layer. **How does the stirrer work?**

5A

1. From top to bottom:	density (g/mL, 20^{o}C)
dodecane	0.749
ethanol	0.789
mineral oil	0.85
water	0.998
wintergreen oil (methyl salicylate)	1.174
salt water (saturated - 26%)	1.197
FC-70 (perfluorotripentylamine)	1.9

2. The stirrer unit has a motor that spins a magnet. The liquids have a magnet encased in plastic that is attracted to the spinning magnet and spins accordingly.

<u>Bonus Questions:</u>

1. Why is the magnet coated with plastic?
2. What properties should the plastic have?
3. Suggest a plastic that has the desirable properties.

Bonus Question Answers.

1. The magnet is coated with plastic to prevent a chemical reaction with the solvent. If the solvent is water, an iron magnet could rust. Additional reactions could occur with other solvents.

2. The plastic should be chemically inert, non-permeable, have a high melting point so that heat does not soften or melt the plastic and preferably a low coefficient of friction so that it will spin easier.

3. Teflon has the desirable properties. Consider the nonstick plastic on the inside bottom of some frying pans. The desired properties are essentially the same and that is why some frying pans are coated with teflon.

Sink or Float. You observed above that sinking vs floating (the solids and liquids in section 4 and the layering of the liquids in section 5) is determined by density. In the waste basket-like container, there are cans of Pepsi, Diet Pepsi, Coca Cola and Diet Coca Cola.

1. **What seems to be unusual about the behavior of the soda cans? Explain your observations.**

The low container of water is available for a float contest. First notice that there are two pieces of aluminum in the container. One is on the top floating and the other has sunk and is on the bottom. The mass of both pieces of aluminum is the same and remember from the earlier table that aluminum is about 2.7 times denser than water.

2. **Why does one piece of aluminum float and the other sink?**

You will be given a square piece of aluminum foil that is the same size as the two in the container (a square with 3 inch (7.6 cm) length sides). The objective is to use only the aluminum to make a floating object that holds as many pennies as possible.

3. **How many pennies does your aluminum float hold?**

6A

1. Floating or sinking is determined by density. But it is important to note that it is the density (mass/volume) of the whole object. For the cola cans, the regular colas contain significant amounts of sugar. The sugar adds enough mass to the contents to make the whole object denser than water. The sweetener in the diet drinks is much sweeter (about 200 times) than sugar and only small amounts are required to make the colas taste about as sweet as the regular colas. Because only small amounts are needed, the density of the whole object is less than the density of water and the diet drinks generally float.

2. For the equal masses of aluminum, the same principle applies. Aluminum has a density of 2.7 g/cm^3 or is 2.7 times as dense as water. Therefore the folded up piece of aluminum sinks. The other piece has been folded up so that the whole object contains considerable air. This makes the volume of the whole object significantly larger and its density much lower than for the folded up piece of aluminum. Thus for the object containing the air, the density of the object is less than the density of water and it floats. The reason steel ships float is that most of the ship is not steel and the mass to volume ratio of the ship is less than the density of water.

3. All of the aluminum boats that are used in the contest have the same mass so the objective is to make the volume of the float as large as possible. The one with the largest volume should hold pennies until its density exceeds that of water.

Mass and density of gases. **How much do you think the air in a 2 quart bottle weighs?** Each of the 2 quart (1.89 L) bottles has been filled with a different gas. The mass of each bottle has been adjusted to **100.00** gram when empty (evacuated) so any amount above 100.00 grams is the mass of the gas in the bottle.

1. **Before you start this, write down on the supplied piece of paper, the top three gases** (not including water - the water content of the air varies between 0 and 4% and water is often the number 3 gas) **that you think are present in dry air.**

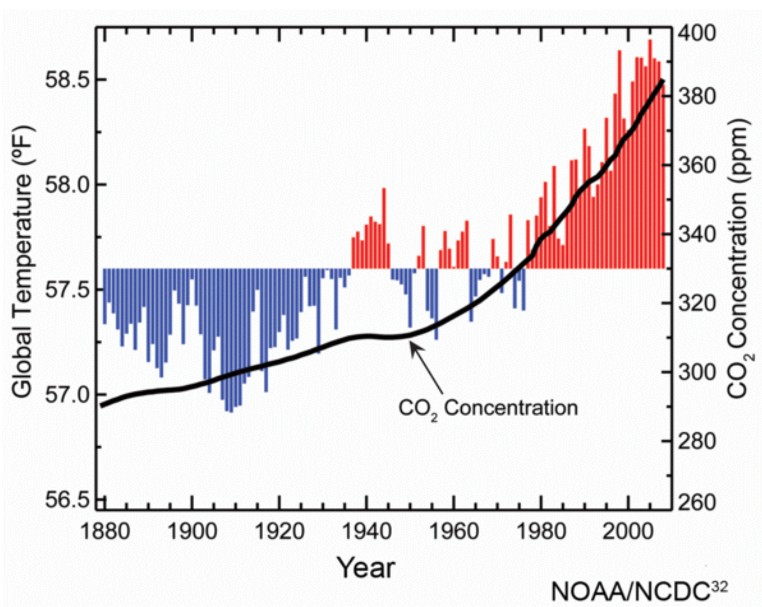
2. **Weigh and record the mass of each bottle. Also weigh a penny. How does the mass of a penny compare to the mass of 2 qts (1.89 Liters) of air?**

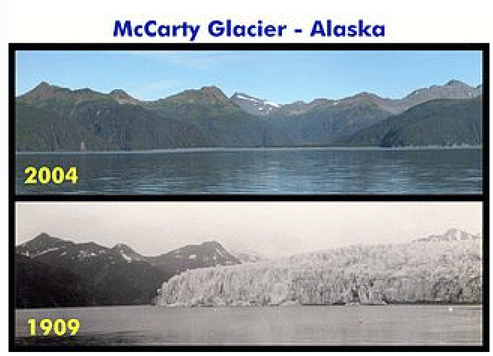
3. **By comparing the masses of each bottle, what conclusion can you come to about the amount of carbon dioxide in the air?**

7A

The weights of the 4 bottles should have resulted in masses of about 2.17g , 2.24 g, 2.48 g, and 3.41 g respectively for the nitrogen, air, oxygen and carbon dioxide in each bottle. This is consistent with the actual contents of the air as the top three gases are nitrogen (78.08%), oxygen (20.95%) and argon (0.93%). The weight of the air bottle is consistent with the air being about 4/5 nitrogen and 1/5 oxygen. More importantly, the results demonstrate that there cannot be a significant amount of carbon dioxide in the air as the higher weight of CO_2 would have made the air weigh much more than 2.24 g. Actually carbon dioxide is the 4th most abundant gas in dry air at only 0.039% CO_2. The most important point here is that there is only a small amount of carbon dioxide in the atmosphere and that is the reason combustion of fossil fuels by humans has been able to raise the value from its pre-industrial revolution value of 0.028% to its current level of 0.039%. At least 90% of scientists agree that the carbon dioxide increase (along with increases of other Greenhouse gases and black carbon) will alter our climate and could cause dangerous changes to regional weather and consequential increases to global temperatures. If we do not act quickly to phase out the use of fossil fuels, we are taking a big risk. If the scientists turn out to be correct and society does not act appropriately, there could be dire consequences to the quality of life. Even if the scientists are incorrect, fossil fuels should be phased out because of air pollution, water pollution (e.g., oil spills), fatalities (mining accidents, oil platform fires, pipeline explosions), wars and other significant problems.

Also, you should have noted that a penny has about the same mass as the air in a 2 qt bottle indicating that the density of air is over one thousand times less than the density of a penny.





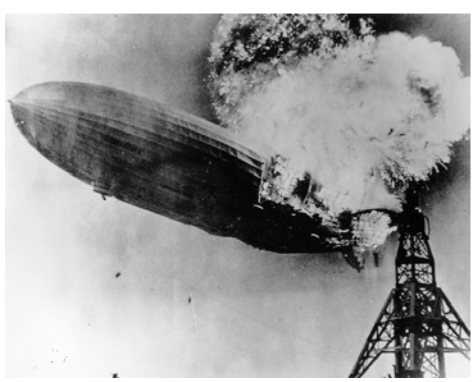
Bonus Questions (Optional)

1. **Why is the egg suspended in the liquids?**

2. **Read the temperature on the Galileo thermometer and explain how the thermometer works.**

3. **Can mass be used (and if so why) to distinguish between pre-1982 and post 1982 pennies. Weigh one of each and find out.**

4. **Party balloons are usually filled with helium to enable them to rise. Early dirigibles were filled with hydrogen which sometimes led to disastrous accidents. The beautiful huge balloons that are used for human transportation are filled with heated air.**



a. **Explain the principle that enables the balloons and dirigibles to float in air.**

b. **Why was the use of hydrogen in a dirigible dangerous?**

5. **Would you expect a bowling ball to float or sink in water. Explain your answer.**

6. **Examples of the densities of some elements and compounds are in the table below. Also included are the strengths of a few of the substances.**

substance	symbol	state (1 atm., 20°C)	density (g/cm^3, 20°C)	strength (MPa)
gold	Au	solid	19.3	100
lead	Pb	solid	11.3	12
copper	Cu	solid	8.92	210
iron	**Fe**	**solid**	**7.86**	**350**
titanium	**Ti**	**solid**	**4.51**	**300**
carbon (diamond)	C	solid	3.51	
carbon (graphite)	C	solid	2.25	
aluminum	**Al**	**solid**	**2.70**	**50**
sodium chloride	NaCl	solid	2.17	
water	H_2O	liquid	0.998	
ethanol	C_2H_6O	liquid	0.789	
titanium bicycle				
octane	C_8H_{18}	liquid	0.703	
oxygen	O_2	gas	0.00133	
air	N_2, O_2, H_2O, Ar	gas	0.0120	
nitrogen	N_2	gas	0.00116	
helium	He	gas	0.000167	
spider silk			1.3	1000
bone			1.7 - 1.8	130
cork			0.24 - 0.35	
wood			0.4 - 0.9	
pine			0.35 - 0.5	
oak			0.75	
polypropylene			0 .85 - 0.95	
acrylic			1.15 - 1.2	
nylon			1.2 - 1.3	
PVC			1.3 - 1.4	
steel			7.7 - 8.1	
brass			8.4 - 8.7	
plastic			0.9 - 1.4	
rubber			0.9 - 1.8	
carbon			2.3	
brass			8.4 - 8.7	

titanium bicycle

Notice that solids are generally a little denser than liquids but both solids and liquids are about a thousand times denser than gases.

All items below bone were added because density cube kits contain some of these materials.

Based on the density and strength values above, why might titanium might be preferred to iron or aluminum?

7. **Explain why the test tubes "disappear" in the liquid.**

8. **Explain how Velcro works (use the magnifying glass to observe the surface of Velcro).**

9. **What is ABCDEFGHIJKLMNOPQSTUVWXYZ** (chemical pun)**?**

10. **The aquarium has dry ice on the bottom. Blow soap bubbles so that the bubbles fall into the aquarium. What do you observe and why?**

8A

1. The jar contains two immiscible liquids. The egg is denser than the top liquid, water, and sinks in it but the egg is less dense than the bottom liquid and floats in it.

2. The objects in the Galileo thermometer have weights adjusted so that the densities of the objects are in a range close to the density of liquid. As the temperature changes, the density of the liquid changes but the density of the objects remain essentially constant. As a result, at any particular temperature, some of the objects are denser than the liquid and sink and those less dense than the liquid float. At high temperatures, the density of the liquid is low enough that all of the objects sink. At low temperatures, the density of the liquid is high enough that all of the objects float. At intermediate temperatures, some sink and some float depending on their densities relative to that of the liquid.

3. Pre-1982 pennies were made out of copper (density = 8.92 g/cm^3). Because of the high cost of copper, post-1982 pennies were made out of zinc (density = 7.14 g/cm^3) and copper coated. Since the volumes (0.35 cm^3) of the pennies are the same, the zinc pennies (2.53 g) weigh about 20% less than the copper ones (3.12 g).

4. a. An object floats if its density (mass divided by volume) is less than its host. In the case of balloons or dirigibles, the host is air. For an air filled balloon, the mass of the balloon includes the rubber and the air. The total is more than the mass of an equivalent volume of air and the balloon sinks in air (the density of the whole object is greater than the density of air). Both hydrogen and helium are very low density gases and even with the mass of the rubber added in, a hydrogen or helium filled balloon or dirigible is less dense than an equivalent volume of air and it floats. Heated air as in a hot air balloon has a lower density than air at ambient temperature and even with the mass of the balloon added in, the hot air balloon has a mass lower than an equivalent volume of air and it floats.

b. While hydrogen and oxygen can coexist together, a little push such as a spark initiates a violent reaction between hydrogen and oxygen to give water.
$2\ H_2\ +\ O_2\ =\ 2\ H_2O\ +\ \text{energy}$
A dirigible that contains hydrogen is always at risk of having the hydrogen oxygen reaction initiated and the dirigible Hindenburg unfortunately exploded and 36 fatalities resulted.

5. A bowling ball has a maximum mass of 16 lbs and a diameter of 8.594 inches or a radius of 10.914 cm. The volume is $4/3\pi r^3$ or 5446 cm^3. The ball will have a density of 0.998 g/cm^3 at 20^{o}C if it has a mass of 5435 g or 12.0 lbs (5435 g/5446 cm^3 = 0.998 g/cm^3). Bowling balls weighing more than 12 lbs should sink and those weighing less than 12 lbs should float.

6. Titanium is almost as strong as iron and much stronger than aluminum. However, titanium has a much lower density than iron. Titanium also has the huge advantage that its properties are relatively insensitive to temperature whereas most metals lose desirable properties as they are heated. The big disadvantage to titanium is that while common in the earth's crust, it is very expensive to refine and right now is not cost competitive with iron or aluminum. Because of the high cost, titanium is used only where its properties outweigh the cost disadvantages (e.g., golf clubs, bicycle frames, space vehicles parts).

7. The liquid in the jar bends light (refracts) about the same amount as glass does. Glass and water refract light different amounts and the glass test tube is visible in water.

8. Velcro has hooks and catches on one piece and catches on the other.

9. Good observers will notice the letters given are not the complete alphabet as the R is missing or gone. Thus the pun represents the third most abundant gas (0.93%) in dry air, argon.

10. Solid carbon dioxide (dry ice) has the unusual property that it does not melt but undergoes sublimation (converts directly from a solid to a gas without passing through a liquid state) to gaseous carbon dioxide directly. As discussed earlier, carbon dioxide is denser than air and tends to stay on near the bottom of the aquarium. The bubbles blown into the tank contain primarily air and even with the added mass of the soap are less dense than carbon dioxide and float on the CO_2 layer. Due to continuous molecular motion, the carbon dioxide will mix with the air and if not continually replenished by more sublimation from the dry ice, the CO_2 layer will disappear and the bubbles will no longer float.

Answer Sheet

2. Masses of ball bearing, cork ring, rubber stopper

	Estimated ranking	Measured Mass (grams)	Actual Ranking
ball bearing	______	_________	______
cork ring	______	_________	______
rubber stopper	______	_________	______

2 Bonus Exercise - For density cubes, write down your rankings on the reverse side and compare to the results in the Table in 8-6.

5. Seven layers of liquids - Name the liquids from the top down

1. top ___________
2. ___________
3. ___________
4. ___________
5. ___________
6. ___________
7. bottom ___________

7. Top 3 gases in dry air: __________ __________ __________

Mass of gas in 4 bottles

air	nitrogen	oxygen	carbon dioxide
__________	__________	__________	__________

2 - 1, 2

Pick each one of the objects up and rank them from lowest mass to highest mass. A form is available for you to record your rankings. Now weigh each object on the centigram balance. Did your estimated rankings agree with the rankings that result from the weighing results? If not, suggest a reason for this discrepant event.

2 - 4

What is the density of water in the metric system? Read the hydrometer in the tall glass cylinder to measure the value.

4

Which substance above exhibits an unusual density relationship between the solid and liquid of the substance?

5 - 1

Based on your observations for the six tubes, determine the order of the layers in the tube containing 7 liquids.

5 - 2

Turn the knob to start and adjust the stirring. How does the stirrer work? (what is causing the stirring?)

6 - 1

What seems to be unusual about the behavior of the soda cans? Explain your observations.

6 - 2

Why does one piece of aluminum float and the other sink?

6 - 3

Use the 3 inch square piece of aluminum to make a boat. How many pennies does it hold before it sinks?

7

1. **Before you start this, write down on the supplied piece of paper, the top three gases** (not including water - the water content of the air varies between 0 and 4% and water is often the number 3 gas) **that you think are present in dry air.**

2. **Weigh and record the mass of each bottle. Also weigh a penny. How does the mass of a penny compare to the mass of 2 qts (1.89 Liters) of air?** Answer: the mass of 2 qts of air and a penny are similar.

3. **By comparing the masses of each bottle, what conclusion can you come to about the amount of carbon dioxide in the air?**

8 - 1

Why is the egg suspended in the liquids?

8 - 2

Read the temperature on the Galileo thermometer and explain how the thermometer works.

8 - 3

Can mass be used (and if so why) to distinguish between pre-1982 and post 1982 pennies. Weigh one of each and find out.

8 - 5

Should the bowing balls float or sink in water?

8 - 7

Explain why the test tubes “disappear” in the liquid.

8 - 8

Explain how Velcro works (use the magnifying glass to observe the surface of Velcro).

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