1865 THE UNIVERSITY OF MAINE

CoSEE CENTERS FOR OCEAN SCIENCES EDUCATION EXCELLENCE

TEACHING SCIENCE BY OCEAN INQUIRY
Density

Seven activities are described below. Explanations are provided after the instructions.

General Comments: In this lab we assume that students are already familiar with the concepts and measurements of mass and volume. For teaching mass and volume using an inquiry-based approach we recommend- “Physics by Inquiry”(L. McDermott et al. 1996. John Wiley and Sons). Concepts associated with measurements and data analysis can be added for any of the activities below (e.g., uncertainties in measurements, precision and accuracy, statistical concepts such as average, standard deviation, and units).

Goals: ***Activities 1-3 (and the optional Activity 7)*** examine the density of solids and can be used to demonstrate that density is not just a function of volume or mass, rather a function of their ratio. They also serve as exercises in measurements of mass and volume and for finding a quantity by calculating its value based on measurements of other quantities. In particular, ***Activity 2*** can be used to address some misconceptions about density and consequences of sinking and floating (e.g., large objects sink, small objects float, wood floats and metal sinks, etc.). It can also serve as an exercise for finding a quantity by calculating its value based on measurements of other quantities. ***Activity 3*** is an example of a discrepant event. ***Activity 4*** examines the density of a fluid (water). ***Activities 5-7*** bring examples for applications of the concept of density to earth science processes.

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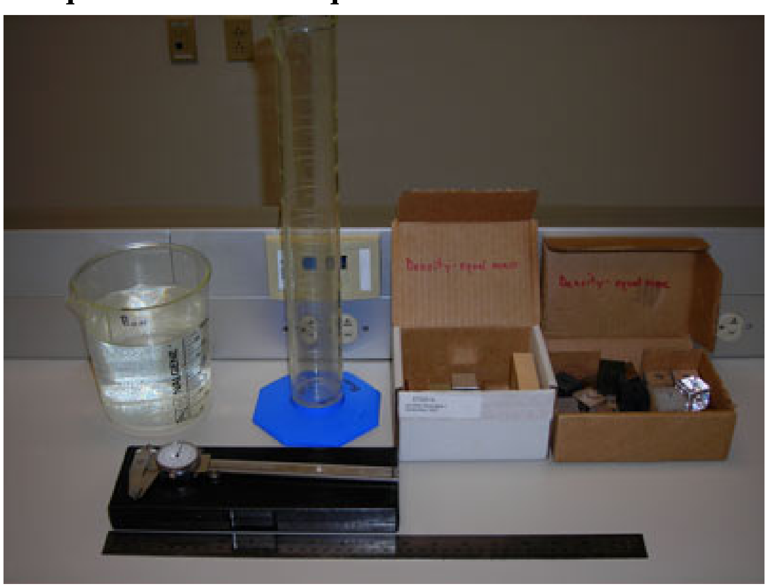
1. Equal Volume and Equal Mass Blocks



Materials:

- Equal volume and equal mass blocks of different substances (obtained from sciencekit.com or Arbor scientific)
- A container with water
- A caliper or ruler
- Scale
- Graduated cylinder wide enough to fit the blocks

Instructions:

1. You have a set of equal volume blocks and a set of equal mass blocks. Measure the volumes and masses of the blocks to make sure this statement is correct. (Note: statistics can be added here: for example what is the precision of your measurement?). Can you suggest more than one method to measure the volume of the cubes? How do the measurements of the different methods you suggested compare?
2. Predict which block will float and which will sink in water? Explain the reasoning for your choices.
3. Test your prediction.
4. Is the sinking/floating behavior of the equal mass blocks similar? Is the sinking/floating behavior of the equal volume blocks similar? What do the results of this experiment indicate?
5. Predict the order of density of the blocks, from the lowest to highest density.
6. Calculate the density of the blocks. How does it fit your prediction from (2)? Can your density measurements explain your observation from (3), assuming that the density of tap water is 1g/cm^3?

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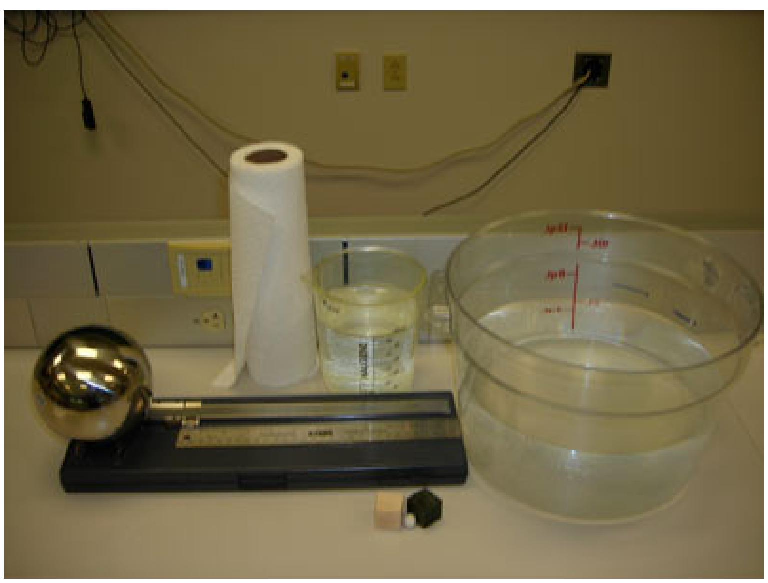
2. Will it Float?



***Materials**:*

- One cube of balsa wood (from sciencekit.com)
- One cube of lignum vitae wood (from sciencekit.com)
- A large hollow metal ball (from sciencekit.com)
- Small Delrin® or other plastic ball (any hardware store)
- A container filled with water (use a big container for the large ball and a small one for the wooden cubes and the small ball)
- A ruler or caliper
- Scale

***Instructions**:*

You have two cubes and two spheres (a large metal one and a small plastic one).

1. Examine the cubes. What are the similarities between them? What are the differences between them?
2. Examine the balls. What are the similarities between them? What are the differences between them?
3. Make a list of properties that you think determines whether an object sinks or floats.
4. Predict which of the items will float in water and which ones will sink. What was the reasoning behind your prediction? Discuss your prediction with your group.
5. Describe how you would test your predictions.
6. Test your approach and predictions. Do your observations support your prediction? If not, how can you explain it?
7. Based on your observations, how would you revise your list of properties from (3)?
8. Measure the densities of the cubes and the balls. Does that explain your observations? (volume of a sphere: $V= 4/3\pi r^3$, where r is the radius)

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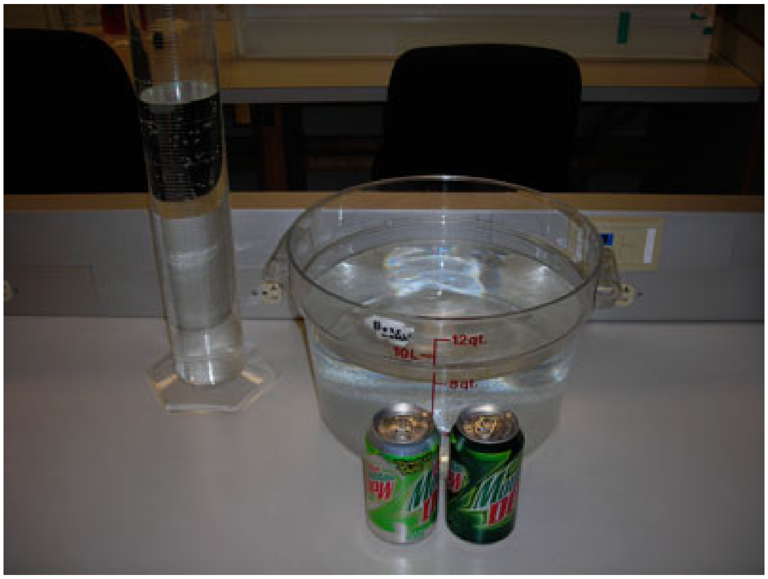
3. Mountain Dew



Materials:

- Cans of Mountain Dew and diet Mountain Dew
- A fish tank or a large container with water.
- Paper towels

Instructions:

1. Examine the two cans. List some similarities and differences between the 2 cans.
2. What do you predict will be the floating and sinking behavior of the cans when you place them in room temperature water? Write the reasoning for your prediction.
3. Place the two cans in the tank. Does your observation agree with your prediction? How would you explain this observation?
4. Wipe off each can and obtain its density (how can you determine it?). Is the density of Mountain Dew smaller/greater than that of tap water? Is the density of diet Mountain Dew smaller/greater than that of tap water?
5. Do your density measurements support your observations? Why would the two differ in density?

4. Density of Fluids

Materials:

- A rectangular tank with a divider
- A salt solution or salt
- Food coloring
- Ice
- Beakers

Instructions:

1. Fill a beaker with room temperature tap water.
2. Place tap water (room temperature) in one compartment of the tank and salt water in the other. Add few drops of food coloring to one compartment.
3. What do you predict will happen when you remove the divider between the compartments? Explain your reasoning?
4. Test your prediction.
5. Measure the densities of the tap water and the salt solution. Do the densities you obtained support your observations?
6. Empty the tank and fill one beaker with hot tap water and one beaker with cold ice water. Add a few drops of food coloring to the beaker with hot water.
7. Place the hot water in one compartment of the tank and the ice cold water in the other. Repeat steps 3-5.

   Put your finger in the fluid. Can you feel the temperature within the different waters? This is analogous to the separation of warm surface waters from deep cold water (i.e., thermocline) that develops in oceans and lakes in the summer.

8. What do these observations tell you about the effect of temperature and salinity on the density of water?

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5. Density of Rocks

Materials:

- Rock samples of basalt (typical of oceanic crust) and granite (typical of continental crust)
- A container with a spout (a large graduated cylinder or a container with graduation will work too)
- Scale

Instructions:

1. You have two rock samples: one of oceanic crust (basalt) and one of continental crust (granite). Given what you know about density, obtain the densities of the rocks (to your aid, you have a graduated cylinder, a container with a spout, and a scale). How do the densities of granite and basalt rocks compare to each other?
2. The average height of land above sea level is 875 m. The average depth of the ocean floor is 3794 m below sea level. Can you use your density calculations and your previous knowledge about the structure of earth to explain this large difference in height between continents and ocean basins? Write your explanation.
3. Textbook values of oceanic crust and continental crust are 2.9-3.0 g/cm^3 and 2.7-2.8 g/cm^3, respectively. How do these values compare to your measurements? If they differ, what may account for the differences between the values you obtained and textbook values?
4. Given that earth's mass is 5.9742 x10^{24} kilograms (a brain teaser: how was this determined?) and that earth's radius is 6,378 kilometers, calculate the average density of earth. How does the average earth's density compare to the density of the rocks? What does it tell you about the structure of earth?

Note: This activity can be modified to include statistical measurements, for example, ask your students to go outside and collect different rocks. Ask them to measure the densities of different rocks (continental crust origin) and calculate the average and standard deviation. You can then ask them to compare measurements and the calculated average to textbook values.

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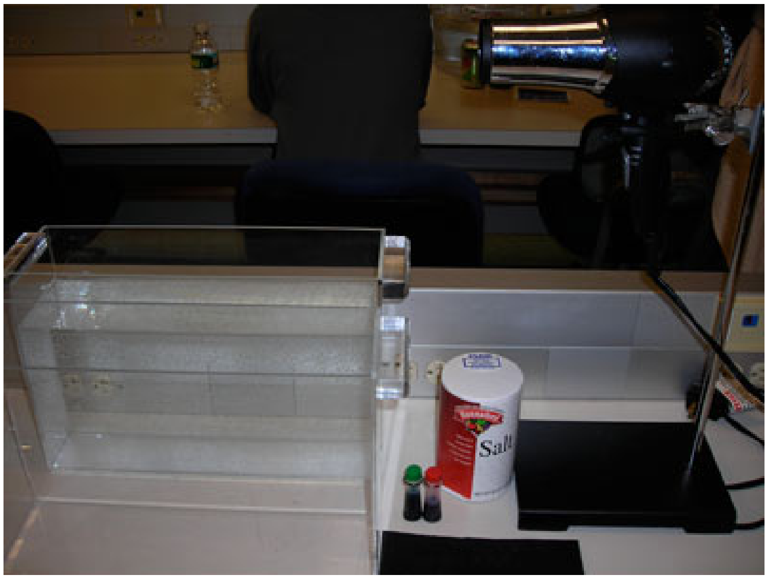
6. Effects of Stratification on Mixing



This activity can be used as a follow up for Activity 4, linking the concept of density and layering in fluids to ocean stratification and mixing.

Materials:

- A tank with tap water
- A tank with stratified fluid (to prepare a stratified solution fill 1/2- 3/4 of the tank with a strong salt water solution. Place a piece of foam over the water and carefully pour warm tap water over it. Remove the foam carefully to avoid stirring)
- Hair dryer
- Food coloring

Instructions:

1. You have two tanks. Fill one tank with tap water. In the other tank you will need to make a stratified water column. Describe how you would do that?
2. Prepare a strong salt solution (add a lot of salt). Fill 1/2-3/4 of the tank with the salt solution. Place a piece of foam over the water and carefully pour tap water over it. Remove the foam carefully to avoid stirring.
3. Which water column, the unstratified or the stratified, will be easier to mix? Why?
4. How would you test your prediction?
5. In each tank, place a few drops of food coloring at the surface layer of the water. Direct the hair dryer parallel to the water's surface, making sure it's set on cold, and blow air

above one tank and then above the other. * DO NOT INSERT THE HAIR DRYER IN THE WATER! * What do you observe?

6. Based on your observations, what do you think will be the effect of global warming on the mixing of ocean and lakes? What could be some of the consequences to marine life?

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7. Optional Activity: Density Rods

This activity can be given as a challenge to more advanced students. It can be used to introduce the term characteristic property, a property such as density that characterizes a particular material or substance. The activity involves measurements (e.g., mass and volume), density calculations, graphing, and reading graphs.

Materials:

- A set of density rods (from sciencekit.com)
- A ruler or caliper
- Scale
- Calculator
- Graphing paper (or graphing program e.g., Excel)
- A container with salt water (a saturated solution)

Instructions:

1. You have a set of 12 black rods of different lengths but the same diameter. Do you think all the rods are made out of the same material? Feel free to use any sensory means to help you evaluate the rods. If you don't think they are all made out of the same material, can you arrange them in groups according to their material? What were your criteria for determining whether a rod belongs to one group or another?

2. Obtain the mass and the volume (volume of a cylinder = $\pi r^2 h$; where r = radius of the cylinder, and h = height) of the 12 rods and plot their volume (X) vs. mass (Y). Do all points fall on the same line? Do you see any pattern in the data?

3. What does the slope of the line represent? What does it tell you about the rods?
4. Calculate the densities of the rods. Do you see any pattern here? How does it compare to the slope(s) of the line(s) from (3)?
5. Can you come up with another method that will allow you to group the rods according to their material properties?

GROUP DEMO: 'Dead Water'

This is a famous oceanographic problem referring to a phenomenon in which a moving boat experiences a mysterious decrease in speed as it travels through water that is vertically stratified (i.e., having a thin fresh or warm water layer over a thick salty or cold layer). What is holding the boat and preventing it from moving at its normal speed? The reason for the decrease in speed is that as the boat moves through the stratified water it generates internal gravity waves at the interface between the two stratified layers (see the waves handout for more about internal waves). Thus, some of the energy that the ship exerts to propel itself forward is used in the generation of the internal waves resulting in the ship slowing down compared to when the water is mixed.

Materials:

- A large rectangular tank (wave tank)
- A boat made out of a dense material (i.e., HDPE) so only its top is above the water line.
- A string (longer than the length of the tank) attached to the boat at one end and to a small weight at the other end).
- Food coloring
- Stopwatch
- Lab Tape

Begin this demonstration with a well-stratified tank (fill the bottom of the tank with colored, strong salt solution). The height of this layer should be set such that the bottom of the boat, when placed in the fresh tap water will contact the salty layer. Carefully pour a layer of fresh tap water over it (see activity 6 for instructions for how to make a stratified water column). Place the boat at one end of the tank and the string + weight on the other end of the tank. Label the starting end of the boat by placing a piece of tape on the wall of the tank. Label another location close to the other end of the tank. Have a student ready with a stopwatch. Have the weight pull the boat across the tank by letting it fall over the side of the tank and measure the time it takes the boat to travel from its start point to the labeled end point. Repeat this measurement several times and calculate the average speed.

Mix the tank and measure again the time it takes the boat to travel between the two marks. How do the averages of your measurements compare?

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DENSITY: EXPLANATIONS FOR LAB ACTIVITIES

1. Equal Volume and Equal Mass Blocks

This is a straight-forward activity in which students observe that the floating and sinking behavior of an object cannot be predicted solely based on its mass or volume, but rather the ratio between them. It can be also used for introducing/practicing different methods for volume measurements: (1) direct measurements of cube dimensions and, (2) measurements of the displacement of a volume of water.

2. Will it Float?

This activity can be used to address some of the misconceptions stated above (e.g., large objects sink, small objects float, wood floats and metal sinks, etc.).

There is a wide range in the densities of wood found throughout the world. The range of density extends from **balsa (0.1-0.17 g/cm^3)** to some tropical hardwoods that have density that exceeds that of water (1.04-1.37 g/cm^3). **Lignum vitae has a density of 1.17-1.29 g/cm^3**.

The volume of the metal ball is 1023 cm^3 and its mass is 144g. Its density is therefore 144/1023= 0.14 g/cm^3.

The volume of the Delrin ball is 1.15 cm^3 and its mass is 1.5 g. Its density is therefore 1.5/1.15= 1.3 g/cm^3.

Given that the density of water is ~1 g/cm^3 (depending on temperature) the balsa and large metal ball will float and the Lignum vitae cube and Delrin ball will sink.

3. Mountain Dew

Density of Mountain Dew- 1.02 g/cm^3 (volume=380 ml [1 ml= 1 cm^3], mass=389 g)
Density of Diet Mountain Dew- 1 g/cm^3 (volume=380 ml [1 ml= 1 cm^3], mass=380 g)

The two cans have the same volume but they differ in the amount of sweetener added, therefore their mass and densities differ.

It will leave a big impression on your students if you weigh out 39 g of sugar and show them the amount (also a lesson in nutrition). We could not find information on the mass of the sweetener that is added to the diet Mountain Dew but the mass of the sweetener in another soda (diet Coke, 12 oz can) is approximately 100 mg. Showing them the masses of sugar and sweetener not only will make your students think twice before they drink another can of soda, but will clearly drive home the message about density.

4. Density of Fluids

Fluids arrange into layers according to their density. When the divider is removed, the denser water (salt water or cold water) sinks to the bottom of the container and the less dense water (tap/fresh or warm water) floats above.

5. Density of Rocks

Density of the basalt sample- 2.8 g/cm^3 (volume=45 ml [1 ml= 1 cm^3], mass=125.5 g)
Density of the granite sample- 2.6 g/cm^3 (volume=53 ml [1 ml= 1 cm^3], mass=136.9 g)

The Earth's crust is made of two types of crust: continental and oceanic. Continental crust is composed mostly of granite while oceanic crust is mostly composed of basalt. Oceanic crust is thinner and denser than continental crust (textbook values: 2.9-3.0 vs. 2.7-2.8 g/cm^3, your measurement may differ from these values because these represent averages over a large sample size of rocks while you measured only one sample from each rock type). Both types of crust overlie the denser mantle of the earth (3.3-5.7 g/cm^3). Because continental crust is less dense than the oceanic crust it "floats" higher on the mantle compared to the oceanic crust. Hence land masses are higher than the ocean floor. Understanding the differences between oceanic and continental crust is crucial for understanding plate tectonics and the formation of ocean basins.

On average, the earth's density is 5.5 g/cm^3. This implies that the earth must be composed of an additional layer/s of higher density then the rocks within its crust. Earth is indeed composed of several layers (crust, mantle, outer core, inner core), with the crust being the least dense layer. The estimated density of the core mantle is 3.3-5.7g/cm^3, the estimated density of the outer core is 10-12 g/cm^3, and the estimated density of the inner core is 12-13 g/cm^3.

The density of the Earth can be computed using Newton's laws:

- Newton's Law of Universal Gravitation states that the force (attractive force) that two bodies exert on each other is directly proportional to the product of their masses (m_1,m_2,) and inversely proportional to the square of the distance between them (L).
- $F=Gm_1m_2/L^2$, where G is the gravitational constant. $G=6.7\cdot10^{-11}$N m^2 kg^{-2}.
- We also know that the force attracting a body to earth is equals to its weight (m) times the gravitational acceleration, g (Newton second law of motion): F=mg, where g=980 cm/s^2. Let m_1 be the mass of earth and m_2 be the mass of a body near the surface of the earth ($F=m_2g$). Thus, $G(m_1m_2)/L^2 = gm_2 \rightarrow Gm_1/L^2 = g$, where L is the radius of the earth.

The mass of the earth is therefore $m_1 = g\cdot L^2/G \sim 6\text{x}10^{24}$Kg. Dividing by the volume of the Earth ($4/3\pi R^3$, where R is the radius of Earth**;** here we used an average of 6372.8 Km) we obtain the Earth's density (5515 Kg/m^3 or 5.5 g/cm^3).

6. Effects of Stratification on Mixing

It requires much more energy to mix a strongly stratified water column compared to a weaker one or an unstratified water column. If you created a strongly stratified water column your 'wind' will not be sufficient to mix two layers and the food coloring will remain at the top layer. In the unstratified (or weakly stratified) case the 'wind' will act to mix the water column resulting in the vertical transport of food coloring from top to bottom until it completely mixes in the water column.

Stratification (due to temperature and/or salinity) is an effective barrier to the exchange of nutrients and gases between surface and deep water. An increase in ocean surface temperature can result in the intensification of the thermocline (i.e., a transition layer that separates upper mixed surface water and deep water. It is defined as the layer at which the largest rate of change of temperature, as a function of depth, occurs) and will prevent the transport of nutrients from deep water to the surface, where phytoplankton reside, and will prevent transport of gases from the ocean surface to depth. The latter can lead to anoxia (lack of oxygen) in deeper water.

The following cartoon (Figure 1) is from a paper by Doney (Nature, 2006; volume 444:695) describing the predicted response of phytoplankton to increased temperatures (and hence stratification) of surface water in mid-and high- latitudes.

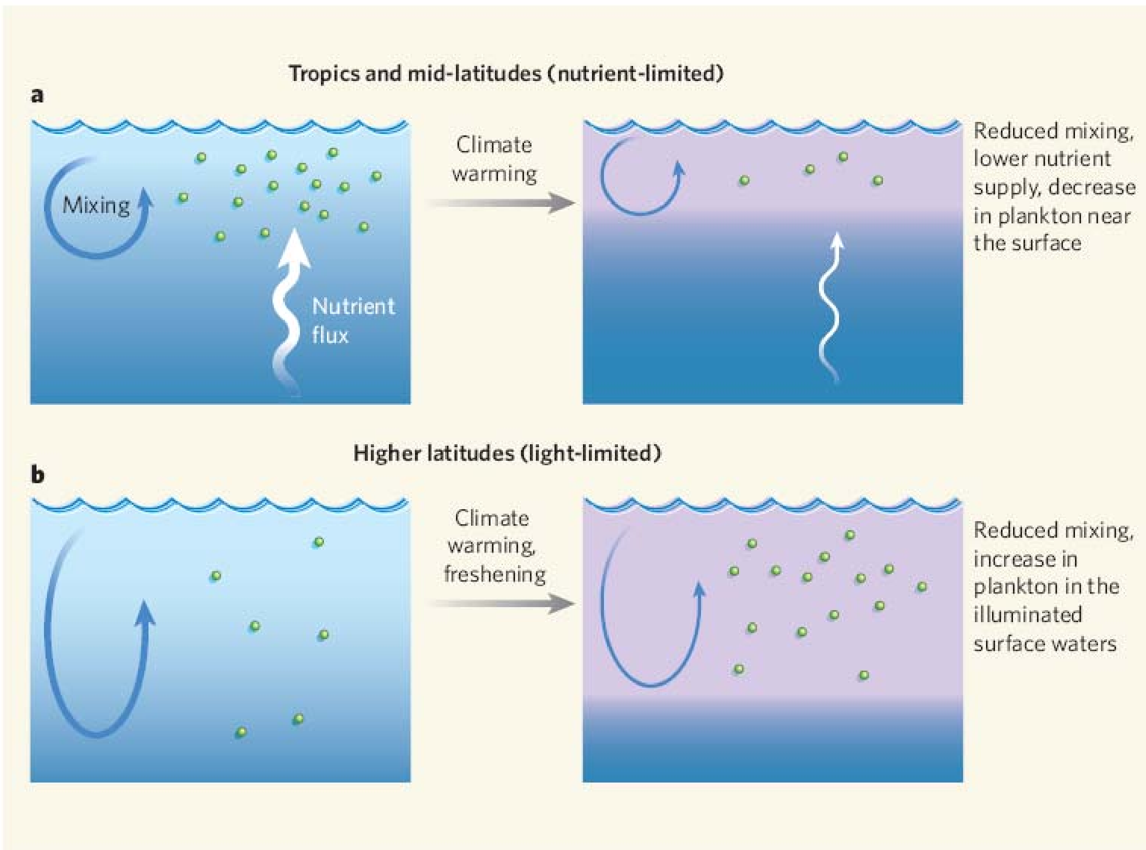

Figure 1 | Predicted phytoplankton response to increased temperature in ocean surface waters[1]. **a**, In the tropics and at mid-latitudes, phytoplankton are typically nutrient-limited, and satellite data tie reduced biological productivity to upper-ocean warming and reduced nutrient supply. **b**, At higher latitudes, the opposite biological response to future warming, and extra freshwater input, may occur. In these regions, phytoplankton are often light-limited; reduced mixing would keep plankton close to the surface where light levels are higher.

7. Density Rods

Table 1 summarizes the mass, volume, and density for each rod.

Table 1
Mass, Volume, and Density of Rods

Length of rod (cm)	Volume (cm^3)	Mass (g)	Density (g/cm^3)
2.5	3.2	3.7	1.16
3	3.8	5.4	1.42
3.5	4.4	5.2	1.18
4	5.1	7.2	1.41
4.5	5.7	6.6	1.16
5	6.4	8.9	1.39
5.5	7.0	9.8	1.40
6	7.6	10.7	1.41
6.5	8.3	11.6	1.40
7	8.9	12.5	1.40
7.5	9.5	11	1.16
8	10.2	14.3	1.40

Figure 2 shows the data points arranged along two lines, where the slope of each line provides the density (1.4 and 1.15 g/cm^3). Compare the slopes with the range of calculated densities in Table 1. While the derived densities are not identical, the small differences within each group are not significant given the uncertainties in the measurements. The data suggest that the rods are made of two different materials. (Caution: if two items have the same density it does not necessarily mean that they are made of the exact same material, however, density can be used as a method to distinguish between different materials). You can group the rods according to their density by placing them in salty water (1.15 g/cm^3 < density < 1.4 g/cm^3) so that the rods with density of 1.15 g/cm^3 will float and the group of rods with a density of 1.4 g/cm^3 will sink.

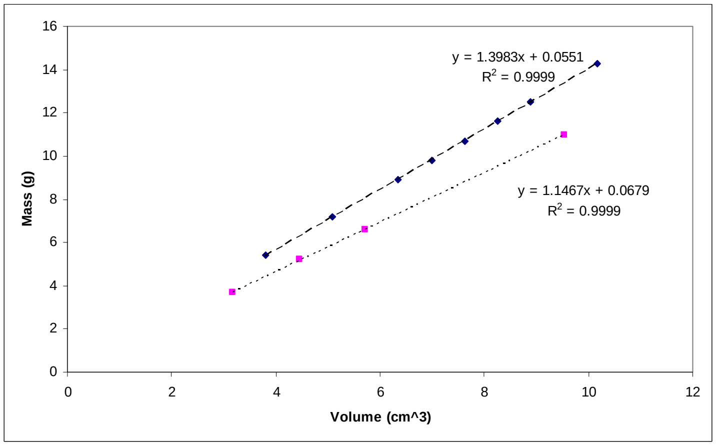

Figure 2. Density of rods.