Chapter 13

Static Fluids

13.1 Density

OALG 13.1.1 Read and interrogate

Read and interrogate Section 13.1 in the textbook and answer Review Question 13.1

OALG 13.1.2 Design an experiment

Equipment: a rock, other pieces of equipment to be determined.

Use a rock (or another solid object) that you find outside to design an experiment to determine its density.

a. Describe your experiment and the data that you will collect.

b. Obtain any necessary equipment, collect and analyze your data, and determine the value of the object's density.

c. How precise is the value you found? Write your finding as an interval.

OALG 13.1.3 Practice

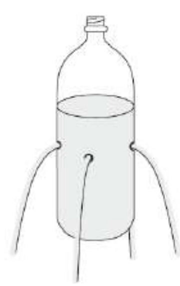
Answer Question 3 on page 408 and solve Problems 1, 6, 8, and 10 on page 409 in the textbook.

13.2 Pressure inside a fluid

OALG 13.2.1 Observe and explain

Equipment: plastic bottle with small holes made around the circumference, a tray to collect water.

Use an opened 32-oz plastic bottle full of water that has been punctured in four places with thumbtacks (to make small holes, put pieces of Scotch tape first and then use the tacks to puncture the bottle). Hold the bottle about 1 m above the tray. Remove the thumbtacks from the bottle and observe the streams of water leaving the bottle.



Explain your observation using the concept of pressure.

OALG 13.2.2 Read and interrogate

Read and interrogate Section 13.2 in the textbook and answer Review Question 13.2

OALG 13.3.3 Practice

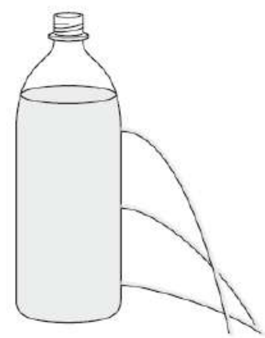
Solve Problems 14, 16, 20, and 21 on pages 409-410 in the textbook.

13.3 Pressure variation with depth

OALG 13.3.1 Observe and explain

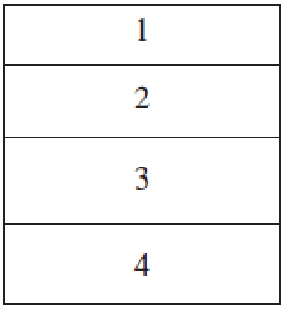
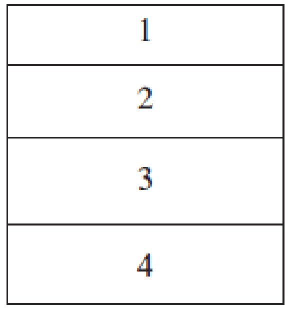
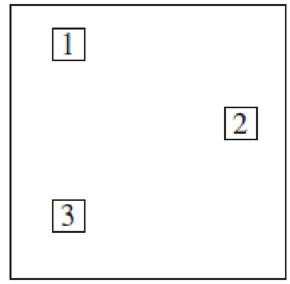
Equipment: a bottle with three holes covered with thumbtacks, tray to collect water.

As shown in the figure, use a plastic bottle with three punctured holes that are closed with thumbtacks. Hold the bottle about 1 m above the tray. Remove the thumbtacks and observe the water streaming out of the holes. Your goal is to explain your observations.



To help explain this experiment, imagine dividing the liquid in the bottle into horizontal layers and examining the forces that the layers exert on each other. Use Newton's third law for reasoning. Fill in the table that follows.

Draw force arrows to indicate the force that layer 1 exerts on layer 2, layer 2 exerts on layer 3, and layer 3 exerts on layer 4. Indicate the relative magnitudes of the forces by the lengths of the arrows.	**Draw force arrows to indicate the force that layer 4 exerts on layer 3, layer 3 on layer 2, and layer 2 on layer 1. Indicate the relative magnitudes of the forces by the lengths of the arrows.**	**Draw arrows representing the pressure that the liquid exerts on very small surfaces inside the liquid shown below. Remember that liquids exert pressure in all directions.**	**Use the drawings in this table to help explain the observations of the experiment with the three thumbtacks.**

Now, use the answers in the table to explain the experiment with the water streams. After you write your explanation here, read and interrogate Section 13.3 in the textbook on pages 391-392. How does your explanation compare to the explanation in the textbook?

OALG 13.3.2 Test your idea

Equipment: a bottle with three holes covered with thumbtacks, tray to collect water.

If the explanation you devised in the previous activity is correct, predict what will happen when you take the same bottle, close the lid, and then remove only the top and the bottom tack at the same time.

a. Predict the outcome.

b. Explain how you made your prediction.

c. Perform the experiment; record the outcome. Sketch what you observed.

d. Do the results of your experiment allow you to reject or gain confidence in your explanation? Explain your reasoning.

OALG 13.3.3 Observe and explain

Equipment: cup with water, a straw.

Fill a cup with water and insert a straw as if you are going to have a sip. Notice the level of water in the straw. Then, tightly cover the top of the straw with your finger and lift the straw from the water. Notice the amount of water in the straw. Sketch what you observe. Draw a force diagram for the water inside the straw. Use the force diagram to explain why the water does not "fall out" of the straw.

OALG 13.3.4 Observe and explain

You slowly lower a pressure sensor into a lake and measure the pressure at different depths in the water (see the table below).

Pressure (N/m^2)	**Distance below surface (m)**
95,000	0
203,000	10
298,000	20
405,000	30

a. Construct a graph of pressure versus depth.

b. Based on the line of best fit for your graph, write a relation between pressure and the distance below the surface of the water.

c. Explain the relation.

d. You repeat the previous experiment, but this time in ocean water. The table below shows the readings of the pressure sensor.

Pressure (N/m^2)	**Distance below surface (m)**
103,000	0
207,000	10
313,000	20
420,000	30

Explain why the readings are different from the readings in the first table. Compare and contrast your explanations with the explanation on page 393 in the textbook.

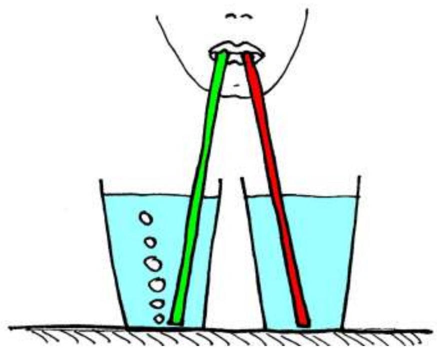
OALG 13.3.5 Observe and explain

Equipment: two identical transparent containers (large plastic cups, glasses or 0.5-liter water bottles with cut tops), two identical straws, sugar.

For this experiment ,you will need to prepare a sugar solution in water. The proportion is about 200 g of sugar per 1 liter of water. For the experiment, you only need about 200 ml of water therefore less sugar (do the calculation).

a. Prepare two identical containers. Pour tap water in one of them and sugar water solution in the other. Make sure the level of water in both containers is the same.

b. Hold the two straws in your mouth and lower their other ends into the water of the two containers so that both straws are almost touching the bottom (but are not in contact with it, see the figure below).



Start blowing into the straws until bubbles come out. In which container do the bubbles come out? Blow a little harder. Can you make the bubbles come out in the other container?

c. Explain your observations and draw graphs of pressure-vs-depth (for help, check the graphs in Conceptual Exercise 13.3 in the textbook). Why do bubbles only come out in one container and not in the other container? How can your graphs explain why you cannot make the bubbles come out of the straw in the second container?

OALG 13.3.6 Observe and explain

Watch the video of the experiment [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-13-3-5] and then proceed to the following questions.

a. Construct a graph of pressure versus depth. Describe which point on the set-up you used to determine the depth.

b. Based on the line of best fit for your graph, write a relation between pressure and the distance of the measuring point below the surface of the water.

c. Explain the relation.

d. Explain why the height of the water column inside the plastic tube increases as the tube is lowered into the water. Suggest the physical law that you can use to predict the height of the water column inside the tube for a particular position of the tube. Indicate any assumptions that you made.

OALG 13.3.7 Test an idea

Equipment: to be determined in the activity.

Two of your friends disagree on how the pressure in a liquid depends on different physical quantities. Ari thinks that the pressure depends only on the depth—the deeper you go in the same liquid, the greater the pressure. Maria thinks that the mass of the liquid above the level at which one measures the pressure matters.

a. Discuss supporting arguments for Ari's and Maria's hypotheses.

b. In words and with a sketch describe an experiment that you can perform to find out whose idea can be ruled out. . (Hint: you can perform an experiment similar to that in Activity 13.2.4 using different width water bottles)

c. Predict the outcome of the experiment based on each hypothesis.

d. Perform the experiment; record the outcome and decide whose hypothesis can be rejected.

OALG 13.3.8 Reason

You drink water from a plastic bottle while traveling on an airplane. When the water is gone, you close the bottle and leave it under the seat. It looks like the bottle in part a. of the figure at right. When the plane lands, you pick up the bottle and, to your surprise, the bottle looks like the bottle in part b. of the figure. Explain this observation by combining your knowledge of molecules, which you acquired in Chapter 12, with your new knowledge of the elevation dependence of fluid pressure that you acquired in this section.

OALG 13.3.9 Test an idea

In the video [https://youtu.be/7Aix6SqEi3A] the experimenter uses a 0.5 liter water bottle with the bottom cut off. In the bottle, there is a 5-mm diameter hole, about ¼ way down from the top. The hole is taped over with masking tape.

a. The bottle (without the cap) is placed into a container with water. The water level is above the taped hole). Watch the water level in the container and inside the bottle. Are they the same? [lvideolink here]

b. Now the experimenter will tightly close the bottle with the cap and lift the bottle up by holding it from the cap. The bottle does not completely leave the water. Observe what happens to the water level inside the bottle [https://youtu.be/U7d2071nsgY]. Explain. Use a pressure-vs-depth graph to justify your explanation.
c. Now, observe what happens when the experimenter removes the tape [https://youtu.be/W0tGw5eGUBI]. Explain. Justify your explanation by using the pressure-vs-depth graph.

OALG 13.3.10 Read and interrogate

Read and interrogate Section 13.3 in the textbook and answer Review Question 13.3.

OALG 13.3.11 Practice

Answer Questions 4, 8, and 9 on page 408 and Problems 30, 37, 38, and 41 on pages 410-411 in the textbook.

13.5 Buoyant force

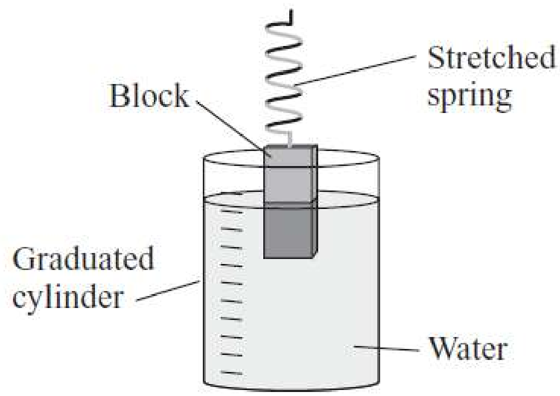
OALG 13.5.1 Observe and explain

a. Observe the experiment [https://youtu.be/_D4U-wen360] and make a list of patterns you notice.
b. Draw force diagrams for the object above water, half submerged and totally submerged at two different depths.

c. What can you conclude about the force that water exerts on the object when it is totally submerged: does it increase with depth or stay constant? Devise an explanation for your conclusion.

OALG 13.5.2 Observe and explain

Experiment: A 2.0-kg block made of aluminum is attached to a Newton spring scale and is slowly lowered into a graduated cylinder filled with water. The experiment is repeated, only this time with a 2.0-kg copper block. The readings of the scales and the readings of the water level at the top surface of the water in the cylinder are shown in the table that follows.



Scale reading for the aluminum block	**Water level in the graduated cylinder**	**Volume of the aluminum block under the water**	**Scale reading for the copper block**	**Water level in the graduated cylinder**	**Volume of the copper block under the water**
19.60 N	200 ml	0	19.60 N	200 ml	0
19.10 N	250 ml	50 ml	19.10 N	250 ml	50 ml
18.60 N	300 ml	100 ml	18.60 N	300 ml	100 ml
18.10 N	350 ml	150 ml	18.10 N	350 ml	150 ml
17.60 N	400 ml	200 ml	17.60 N	400 ml	200 ml
15.60 N	600 ml	400 ml	17.36 N	424 ml	224 ml (just submerged)
13.60 N	800 ml	600 ml	17.36 N	424 ml	224 ml (deeper in water)
12.20 N	940 ml	740 ml (just submerged)	17.36 N	424 ml	224 ml (even deeper)
12.20 N	940 ml	740 ml (deeper in water)	17.36 N	424 ml	224 ml (even deeper)

a. Use the data in the table to find a pattern in the magnitude of the upward force that the water exerts on each block. *Hint:* Remember that the density of water is $1000\ \text{kg/m}^3$.

b. After the copper block is completely submerged, the scale reads 17.36 N. After the aluminum block is completely submerged, the scale reads 12.20 N. Both readings do not change when the blocks are lowered deeper under the water. Are these results consistent with the findings in Activity 13.6.1?

OALG 13.5.3 Observe and explain

The experiment described in the previous activity is repeated again, but this time the blocks are lowered into vegetable oil. Use the data recorded in the table below to find a pattern in the magnitude of the upward force that the oil exerts on each block. *Hint:* Remember that the density of oil is $900\ \text{kg/m}^3$.

Scale reading for the aluminum block	**Oil level in the graduated cylinder**	**Volume of the aluminum block under the oil**	**Scale reading for the copper block**	**Oil level in the graduated cylinder**	**Volume of the copper block under the oil**
19.60 N	200 ml	0	19.60 N	200 ml	0
19.16 N	250 ml	50 ml	19.16 N	250 ml	50 ml
18.70 N	300 ml	100 ml	18.70 N	300 ml	100 ml
18.26 N	350 ml	150 ml	18.26 N	350 ml	150 ml
17.80 N	400 ml	200 ml	17.80 N	400 ml	200 ml

OALG 13.5.4 Explain

a. In Activities 13.5.2 and 13.5.3, what pattern emerges between the volume of the object in the liquid and the effect of the liquid in supporting the object?

b. Use this pattern to devise an expression for the lifting force exerted by a liquid on an object that is partly or totally submerged in the liquid.

c. Read and interrogate Section 13.5 in the textbook and compare your answer in part b to Equation 13.5.

OALG 13.5.5 Test your ideas

Equipment: Container with oil and a container with water.

Predict what will happen when you pour water into a glass beaker partially filled with oil. Use the values for the densities of water and oil on page 387 in the textbook and your knowledge of buoyant force to make your prediction. Then, perform the experiment and record the result. Did your prediction match the outcome?

OALG 13.5.6 Derive

In Activities 13.5.1–13.5.3, you determined that a liquid exerts an upward force on submerged objects.

a. Explain *how* the liquid pushes up on a submerged object.

b. Explain why the liquid would be expected to exert an upward force on a submerged object that is equal to the force that Earth exerts on the liquid displaced by the submerged object. *Hint:* Think about what the liquid supports when the object is not occupying that particular volume.

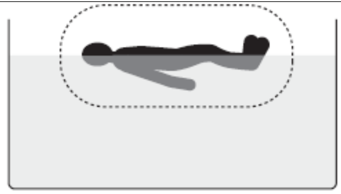
OALG 13.5.7 Practice

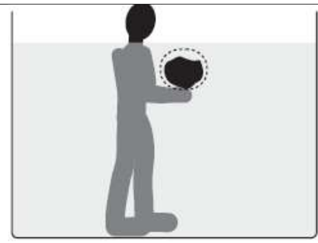
Answer Questions 6, 7, 10, 15, and 16 on page 409 and solve Problems 51, 55, 59, 61, and 62 on pages 411- 412 in the textbook.

13.6 Skills for analyzing static fluid problems

OALG13.6.1 Represent and reason

Word descriptions and pictorial representations are provided below for two situations involving buoyant force. Complete the table that follows.

Word description	**Pictorial representation (the system is circled)**	**Construct a force diagram for the system.**	**Apply Newton's second law in component form for the system.**
A person of density $980\ \text{kg/m}^3$ floats while partially submerged in salt			

water of density $1030\ \text{kg/m}^3$.			
You hold a 40-kg rock of density $2300\ \text{kg/m}^3$ that is completely submerged in water of density $1000\ \text{kg/m}^3$.			

OALG 13.6.2 Regular problem

Read the problem below. Then use the problem solving strategy outlined in the table to solve it.

Suppose your mass is 70.0 kg and your density is 970 kg/m^3. If you could stand on a scale in a vacuum chamber on Earth's surface, the reading of the scale would be $mg = 70.0\ \text{kg}\left(9.80\ \text{N/kg}\right) = 686\ \text{N}.$ What will the scale read when you are completely submerged in air of density 1.29 kg/m^3?

Sketch and translate • Make a labeled sketch of the situation and choose the system of interest. If applicable, decide on the initial and final states. • Include all known information in the sketch and indicate the unknown(s) you wish to determine.	
Simplify and diagram • Indicate any assumptions you are making. • Identify objects outside the system that interact with it. • Construct a force diagram for the system, including a vertical coordinate axis. The buoyant force is just one of the forces included in the diagram. • Construct a bar chart or any other graphical representation that might help solve the problem.	

Represent mathematically • Use the force diagram to help apply Newton's second law in component form. • Use the energy bar chart to calculate work and energy if needed. • Use the expression for buoyant force and the definitions of pressure and density if needed; sometimes you might need the ideal gas law.	
Solve and evaluate • Insert the known physical quantities and solve for the desired unknown. • Evaluate your final result in terms of units, reasonable magnitude, and whether the answer makes sense in limiting cases.	

OALG 13.6.3 Equation Jeopardy

Below we present mathematical representations of various processes in fluids. For each representation:

a. Sketch a situation that might be described by the representation.

b. Describe the situation in words.

c. Draw a force diagram for an object of interest (for parts **b**. and **c**. only).

Mathematical representations of the processes:

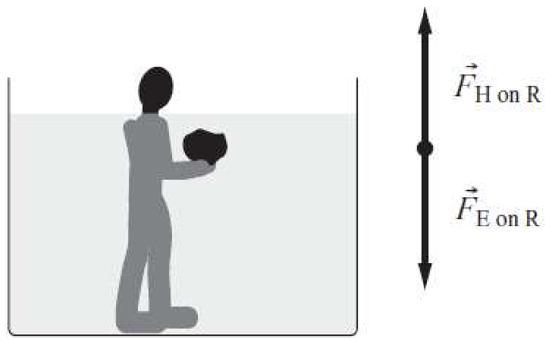
1. $\left(1.6\times 10^{5}\ \text{N/m}^{2}\right)-\left(1.0\times 10^{5}\ \text{N/m}^{2}\right)=\left(1000\ \text{kg/m}^{3}\right)\times\left(9.8\ \text{N/kg}\right)\left(0.0\ \text{m}-y_{1}\right)$

2. $F+\left(1000\ \text{kg/m}^{3}\right)\times\left(9.8\ \text{N/kg}\right)\left(0.010\ \text{m}^{3}\right)-\left(24\ \text{kg}\right)\left(9.8\ \text{N/kg}\right)=0$

3. $\left(1000\ \text{kg/m}^{3}\right)\times\left(9.8\ \text{N/kg}\right)V_{\text{displaced water}}-\left(24\ \text{kg}\right)\left(9.8\ \text{N/kg}\right)=0$

OALG 13.6.4 Evaluate the solution

The problem: You slowly lift a 20-kg rock of density 2400kg/m^3 from the bottom of a lake near the shore. Determine the force that you must exert on the rock while lifting it when it is under the water. Assume that $g = 10$ N/kg.



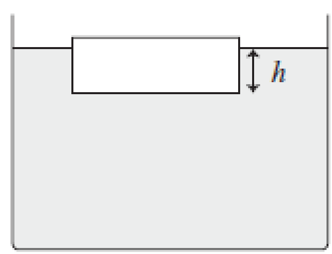
Proposed solution: Because you lift it slowly, the rock is not accelerating $(a = 0)$. A sketch of the situation and a force diagram for the rock (the system) are shown above. Applying the vertical component form of Newton's second law, we find:

$$+F_{\text{H on R}} + (-F_{\text{E on R}}) = 0 \text{ or } F_{\text{H on R}} = F_{\text{E on R}} = mg = (20\text{ kg})(10\text{ N/kg}) = 200\text{ N}$$

a. Identify any missing elements or errors in the solution.

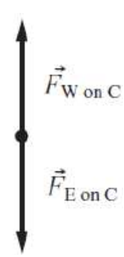
b. Provide a corrected solution if there are any missing elements or errors.

OALG 13.6.5 Evaluate the solution



The problem: A $3.0\text{-m} \times 1.0\text{-m}$ rectangular plastic container that is 1.0-m high has a mass of 1500 kg. The container floats in fresh water (density 1000kg/m^3), partially submerged. Find the depth of the container that is submerged in water (marked as *h* in the figure at right). Assume that $g = 10\text{N/kg}$.

Proposed solution: The container is floating and has zero acceleration $(a = 0)$. A force diagram for the $(3.0\text{m})(1.0\text{m})(1.0\text{m}) = 3.0\text{-m}^3$ container (the system) is shown at right. Applying the vertical component form of Newton's second law, we find:



$$\Sigma F_y = 0$$

$$+F_{\text{WonC}} - F_{\text{EonC}} = 0$$

$$\rho gV - mg = 0$$

$$\left[(1500\text{kg})/(3.0\text{m}^3)\right](10\ \text{N/kg})(3.0\text{m}\cdot 1.0\text{m}\cdot h)-(1500\text{kg})(10\text{N/kg})=0$$

$$h = 3.0\text{m}$$

a. Identify any missing elements or errors in the solution.

b. Provide a corrected solution if there are any missing elements or errors.

OALG 13.6.6 Test different explanations

You place a plastic container with water on a scale and observe the reading (see the figure on the left below). Then, you hang a 1-kg object from a string and submerge it in the water so that the bottom of the object does not touch the bottom of the container (see the figure on the right below). You notice that the scale reading increases and the water level goes up. Your friends suggest the following explanations for the increase in the scale reading:

Scale reading: 620 g

Scale reading: 750 g

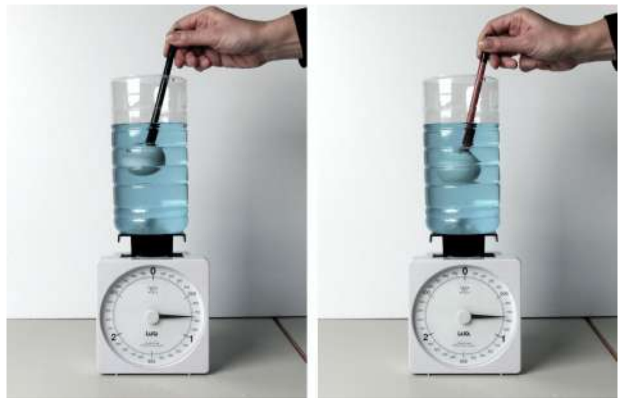
Finn: The water exerts an upward force on the submerged object. According to Newton's third law, the object consequently exerts a force on the water that is an equal in magnitude and opposite in direction (downward). This force makes the water press harder on the container and the container press harder on the scale.

Dimitry: Some mass of the immersed part of the object adds to the mass of the water. As a result, the force exerted by the container on the scale increases.

Alex: The immersed object exerts no force on the water, but it does make the water rise. The higher the level of the water, the more pressure on the bottom surface of the container. Consequently, this causes a larger the force to be exerted by the container on the scale.

While testing their explanations, your friends designed the following testing experiments:

Testing experiment 1



Testing experiment 2

Testing experiment 1: Squeeze the container to achieve the same increase in water level as when immersing the 1-kg object. Record the reading of the scale.

Testing experiment 2: Submerge in the water a ping-pong ball fixed on the end of a thin stick and record the change in the scale reading. Then, repeat the experiment with a ping-pong ball filled with sand.

a. Before reading on, make predictions for the outcome of each testing experiment based on each explanation proposed by your friends.

The outcomes of the testing experiments are as follows:

Outcome of TE1: The scale reading is 620 g (note: the cardboard “squeezers” were also on the scale in the original experiment)

Outcome of TE2: In both cases, the scale reading increases by 30 g.

b. Compare the outcomes of the testing experiments with your predictions and decide which explanation(s) you can reject and which you cannot reject.

c. Based on the explanation(s) that you were not able to reject, draw a force diagram for the water-container object. Draw another force diagram for the 1-kg object in the case when the 1-kg object is immersed in the water (as is the case in the figure on the right at the beginning of this activity).

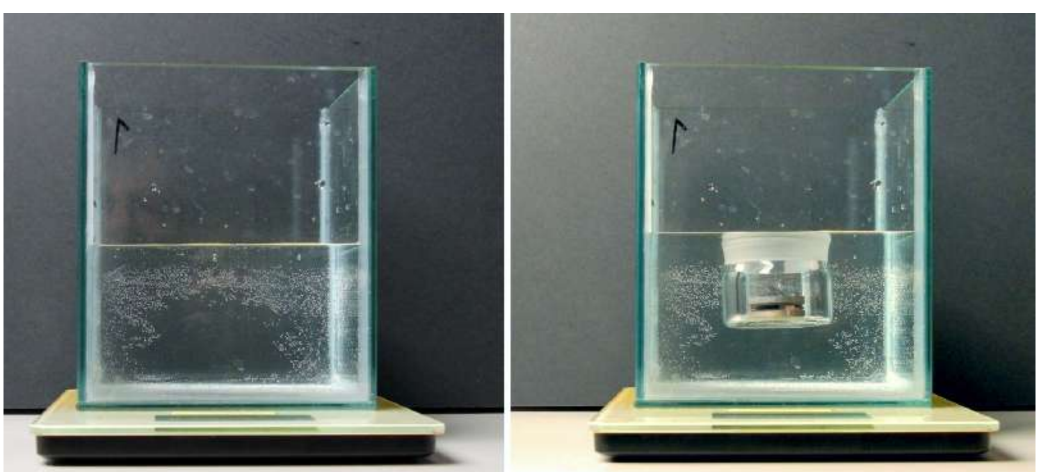
d. Try to explain the outcome of testing experiment 1. (*Hint:* draw the forces that the water in the container exert on different parts of the container's walls.)

OALG 13.6.7 Analyze

You have a scale, a small glass beaker, a metal object, and a square glass container (base 130 mm × 130 mm, height 150 mm) with water (see the figure below, from left to right).

First, you zero the scale. Then you put an empty small glass beaker on the scale and record the mass: $m_{\mathrm{GB}} = 33$ g. Then you put the square glass container including water on the scale and record the mass: $m_{\mathrm{CW}} = 1851$ g (see the next figure, photo on the left).

Then you put the metal object on the bottom inside the small glass beaker and carefully place them both on the surface of the water. When you release the beaker, it floats with its upper edge just aligned with the water surface but no water enters the beaker (see the next figure, photo on the right). At this point, you record a new scale reading $m_{\mathrm{CWBO}} = 1927$ g.

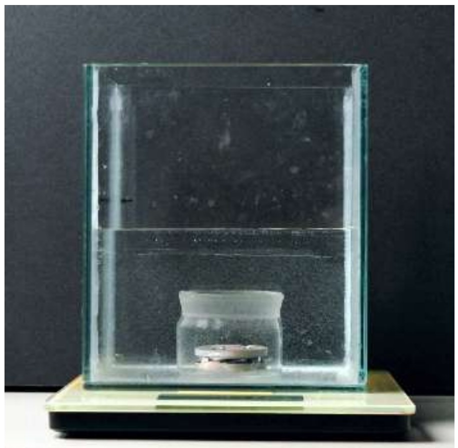


a. Estimate the volume of the small glass beaker based on the measured masses. How else can you estimate the volume of the glass beaker? Describe a second method. Indicate any assumptions that you made. Compare the results from the two methods. Are the results of these two methods consistent with each other?

b. Estimate the mass of the metal disk.

c. Estimate the volume of the water in the glass container.

d. You slightly push the small glass beaker that is floating so that the water fills the beaker and it sinks to the bottom (see the figure below). Predict the final reading of the scale.



OALG 13.6.8 Observe and explain

Observe the video of a test tube with some ball bearings in water [https://youtu.be/VxTkQTFVvzk]

a. Describe what you observe. What kind of motion does the test tube undergo? How do you know?

b. Draw two motion diagrams for the upward motion of the tube (one when the test tube starts moving up and the other one when the test tube approaches the top of the upward motion). Then draw corresponding force diagrams for one point of each motion diagram.

c. Repeat part **b** for the downward motion (the beginning and before the test tube stops and reverses direction).

d. When does the test tube have its maximum kinetic energy? Where does the kinetic energy of the moving test tube come from? Explain using a bar chart. State your chosen system and describe the initial and final states

e. Use the data in the video to determine the period and amplitude of vibrations. The video is recorded in real time at 30 frames per second.

OALG 13.6.9 Read and interrogate

Read and interrogate Section 13.6 in the textbook and answer Review Question 13.6.

OALG 13.6.10 Practice

Answer Questions 37-39 on page 409 and solve Problems 66, 70, 73, 74, 76, 88, and 89 on pages 412-413 in the textbook.