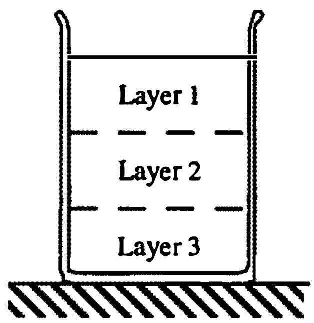
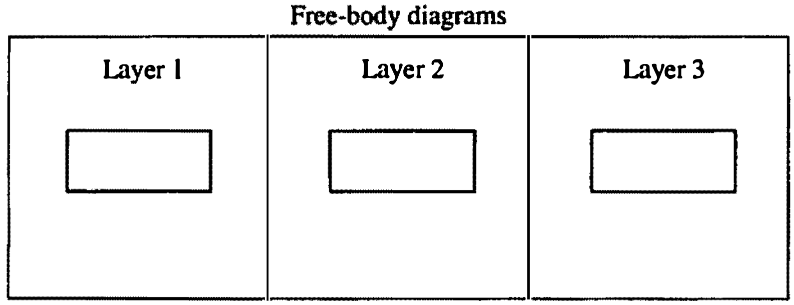
## I. Applying Newton's laws to liquids

A rectangular container filled with water is at rest on a table as shown. Two imaginary boundaries that divide the water into three layers of equal volume have been drawn in the diagram. (No material barrier separates the layers.)




A. For each layer, draw a free-body diagram in the space provided. Be sure to indicate on your diagram the surface on which each *contact* force is applied. (This is usually done by placing the tip of the arrow that represents the force at that surface.)

The label for each force should indicate:
- the type of force,
- the object on which the force is exerted, and
- the object exerting the force.

B. Rank the magnitudes of all the vertical forces you have drawn in the three diagrams from largest to smallest. Explain how you determined your ranking.

How does the weight of layer 1 compare to that of layer 3?

A liquid in which equal volumes have equal weight regardless of depth (*i.e.*, the density does not vary) is referred to as *incompressible*. Assume that all liquids in this tutorial are incompressible.

C. Imagine that a small hole is opened in the container wall near the bottom of each layer.

1. Predict what will happen to the water near each hole. Explain.

2. Check your prediction by observing the demonstration. Record your observations. (A sketch may be helpful.)

   What do your observations suggest about: (1) the *existence* of horizontal forces on the three layers of water in part A? (2) the *relative magnitudes* of the horizontal forces on the three layers?

   If necessary, revise your free-body diagrams in part A so that they are consistent with your answers.



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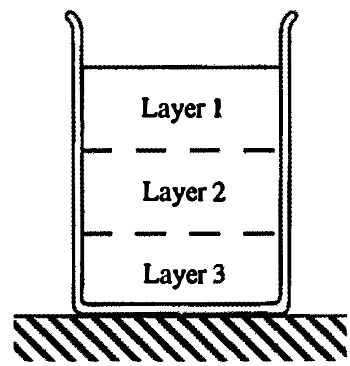
## II. Pressure and force

A. Recall the relationship between force and pressure. (Consult your textbook if necessary.) Below we will apply this relationship to the three layers from part I.

1. Which *force* would you use to determine the *pressure* at the bottom of layer 2? (There may be more than one correct answer.) Explain your reasoning. (*Hint:* Refer to your free-body diagrams from section I. Which forces are exerted at the bottom of layer 2?)

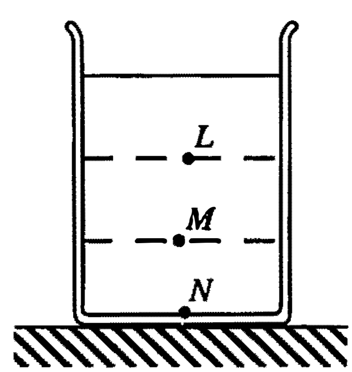



2. Which *area* would you use to determine the pressure at the bottom of layer 2? Explain.

3. Suppose that you wanted to determine the pressure at a point in the center of layer 2. For what object(s) would you draw a free-body diagram? Which force and which area would be useful in determining the pressure?

B. Suppose you wanted to determine the pressure at the top surface of layer 1. Which force would you use to determine this pressure? If necessary, modify your free-body diagrams to include this force. Be sure to label your diagram to indicate the object that exerts this force.

Three points, *L*, *M*, and *N*, are marked at the bottom of the three layers.



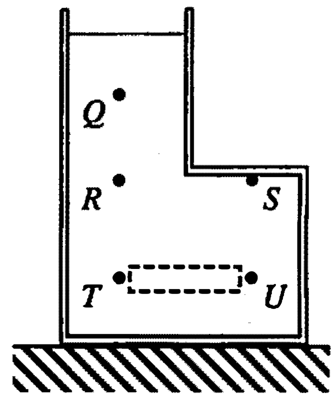

C. Rank the pressures at points *L*, *M*, and *N*. Explain how your answer is consistent with your ranking of forces in section I.

The pressure *P* at a point in an incompressible liquid is often described mathematically as $P = P_o + \rho g h$.

D. Is your ranking in part C consistent with this equation? (*Hint:* At what point is $h = 0$? What is the pressure at that point?)

## III. Pressure as a function of depth

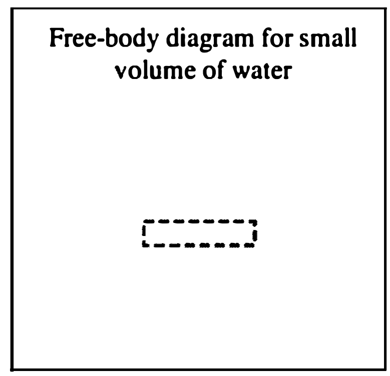
The container at right is filled with water and is at rest on a table. An imaginary boundary that outlines a small volume of water has been drawn in the diagram. Treat this small volume of water as a single object.




A. Draw a free-body diagram for the small volume of water in the space below the figure.

B. Compare the magnitudes of the *horizontal* forces that you have drawn.

Is your answer consistent with the motion of the small volume of water? Explain.




C. Use your answer to part B to compare the pressures at points $T$ and $U$. (*Hint:* How is the pressure at point $T$ related to the force on the small volume of water by the water to its left?)

D. Rank the pressures at points $Q$, $R$, $S$, $T$, and $U$. Explain.

E. Consider the following student dialogue:

Student 1: *"The pressure at a point is equal to the weight of the water above divided by the area. Therefore the pressure at point R is greater than the pressure at point S because there's no water above point S."*

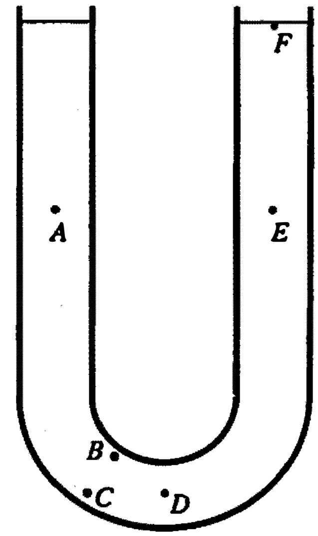
Student 2: *"I agree. The pressure is $P_0 + \rho gh$, and h is zero for point S and greater than zero for point R. Therefore, the pressure at R must be greater."*

Do you agree with either student? Explain your reasoning.

➪ Discuss your reasoning with a tutorial instructor.

## IV. Pressure in a U-tube

A U-shaped tube is filled with water as shown.

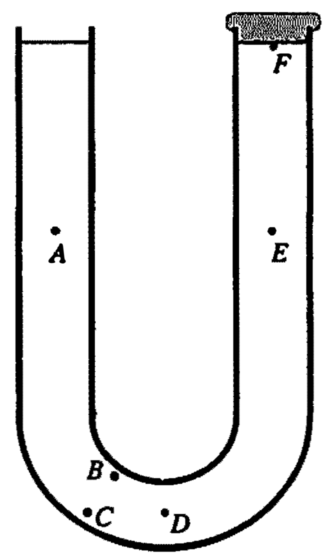



A. Rank the pressures at points *A* through *F*. Explain.

Is your ranking consistent with the equation $P = P_0 + \rho gh$? Explain.

B. The right end of the tube is now sealed with a stopper. The water levels on both sides remain the same. There is no air between the stopper and the water surface.

1. Does the pressure at points *A* and *D* *increase, decrease,* or *remain the same?* Explain.



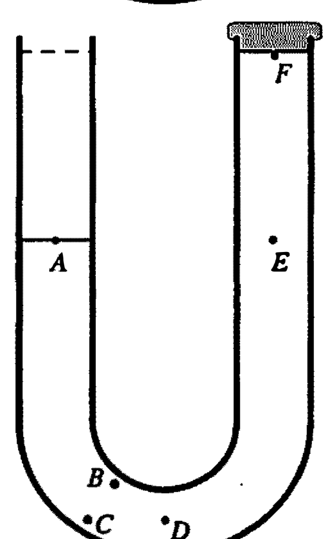

2. Is the pressure at point *E* *greater than, less than,* or *equal to* the pressure at point *D?*

   Does the difference in pressure $\Delta P_{DE}$ between points *D* and *E* change when the stopper is added? Explain.

3. Is the pressure at point *F* *greater than, less than,* or *equal to* atmospheric pressure?

   Is the force exerted by the rubber stopper on the water surface on the right *greater than, less than,* or *equal to* the force exerted by the atmosphere on the water surface on the left?

C. A syringe is used to remove some water from the left side of the U-tube. The water level on the left side is seen to be lowered, but the water level on the right does not change.




Consider the following student dialogue:

Student 1: *"The pressure at point F must now be higher than atmospheric pressure because the water there is being pushed up against the stopper."*

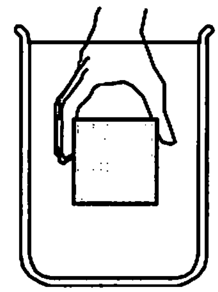
Student 2: *"I think that the pressure at point E must be the same as at point A because they are at the same level. These points are both at atmospheric pressure. So the pressure at point F is lower than atmospheric pressure because we know that pressure gets less as you go up."*

Student 3: *"But water is more dense than air so the pressure at F cannot be less than atmospheric pressure."*

With which student(s), if any, do you agree?

## I. Buoyant force

A. A cubical block is observed to float in a beaker of water. The block is then held near the center of the beaker as shown and released.



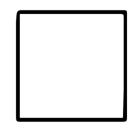
1. Describe the motion of the block after it is released.

2. In the space provided, draw a free-body diagram for the block at the instant that it is released. Show the forces that the water exerts on each of the surfaces of the block separately.

   Make sure the label for each force indicates:

   - the type of force,
   - the object on which the force is exerted, and
   - the object exerting the force.

Free-body diagram for block at instant it is released



3. Rank the magnitudes of the vertical forces in your free-body diagram. If you cannot completely rank the forces, explain why you cannot.

   Did you use the relationship between pressure and depth to compare the magnitudes of any of the vertical forces? If so, how?

   Did you use information about the motion of the block to compare the magnitudes of any of the vertical forces? If so, how?

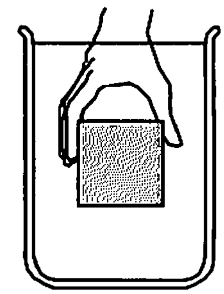
4. In the box at right, draw an arrow to represent the vector sum of the forces exerted on the block by the surrounding water. How did you determine the direction?

   Sum of forces on block by water

   Is this vector sum the *net force* on the block? (Recall that the net force is defined as the vector sum of *all* forces acting on an object.)

   Is the magnitude of the sum of the forces exerted on the block by the water *greater than*, *less than*, or *equal to* the weight of the block? Explain.

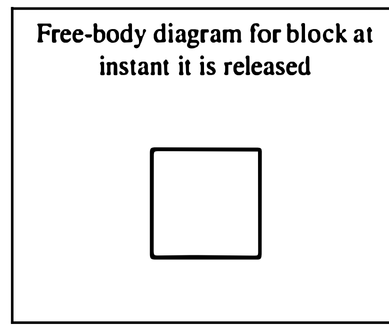
B. The experiment is repeated with a second block that has the same volume and shape as the original block. However, this block is observed to sink in water.



1. In the space provided, draw a free-body diagram for the block at the instant it is released. As before, draw the forces exerted on each surface of the block by the water.

2. Compare the free-body diagram for the block that sinks to the one you drew in part A for the block that floats.

   Which forces are the same in magnitude and which are different? (*Hint:* How does the pressure at each surface of this block compare to the pressure at the corresponding surface of the block in part A?)




   Do any forces appear on one diagram but not on the other?

3. In the space provided, draw an arrow to represent the vector sum of the forces exerted on the block by the water.

   How does this vector compare to the one you drew for the block that floats? (Consider both magnitude and direction.)

Sum of forces on block by water

C. Imagine that you were to release the block from part B at a much greater depth. State whether each of the following forces on the block would be *greater than, less than*, or *equal to* the corresponding force on the block in part B above:

1. the upward force on the bottom surface on the block.

2. the downward force on the top surface of the block.

3. the vector sum of the forces on the block by the surrounding water. (*Hint:* Does the difference between the pressures at the top and bottom surfaces of the block change?)

The vector sum of the forces exerted on an object by a surrounding liquid is called the *buoyant force.* This force is customarily represented by a single arrow on a free-body diagram.

D. In general, does the buoyant force on an object that is completely submerged in an incompressible liquid depend on:

- the *mass* or *weight* of the object?

- the *depth* below the surface at which the object is located?

- the *volume* of the object?

➪ Check your answers with a tutorial instructor before continuing.

## II. Displaced volume

Consider two blocks of the same size and shape: one made of aluminum; the other, of brass. Both blocks sink in water. The aluminum block is placed in a graduated cylinder containing water. The volume reading increases by 3 mL.

A. By how much does the volume reading increase when the brass block is placed in the cylinder? (Assume that no water leaves the cylinder.) Explain.

When an object is placed in a graduated cylinder of liquid, the increase in the volume reading is called the *volume of liquid displaced* by the object.

B. Does the volume of water displaced by a *completely submerged* object depend on

- the *mass* or *weight* of the object?

- the *depth* below the surface at which the object is located?

- the *volume* of the object?

- the *shape* of the object?

## III. Archimedes' principle

According to *Archimedes' principle*, the magnitude of the buoyant force exerted on an object by a liquid is equal to the weight of the volume of that liquid displaced by the object.

A. Consider the following statement made by a student:

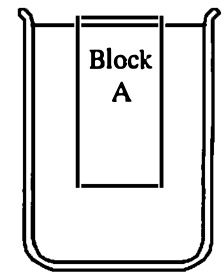
> *"Archimedes' principle simply means that the weight of the water displaced by an object is equal to the weight of the object itself."*

Do you agree with the student? Explain.

## IV. Sinking and floating

A. A rectangular block, A, is released from rest at the center of a beaker of water. The block accelerates upward.

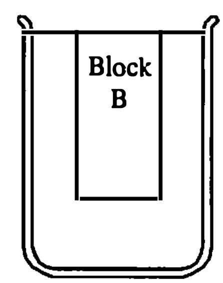
1. At the instant it is released, is the buoyant force on block A *greater than, less than,* or *equal to* its weight? Explain.




2. When block A reaches the surface, it is observed to float at rest as shown. In this final position, is the buoyant force on the block *greater than, less than,* or *equal to* the weight of the block? (*Hint:* What is the net force on the object?)

3. Are your answers to the questions above consistent with Archimedes' principle? (*Hint:* How does the volume of water displaced when the block is floating compare to that displaced when it was completely submerged?)

B. A second block, B, of the same size and shape as A but slightly greater mass is released from rest at the center of the beaker. The final position of this block is shown at right.




How does the buoyant force on block B compare to the buoyant force on block A:

- at the instant they are released? Explain.

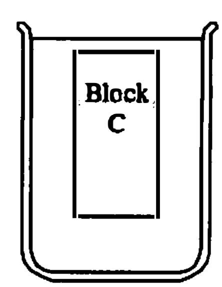
- at their final positions? Explain.

C. A third block, C, of the same size and shape as A and B but with slightly greater mass than block B is released from rest at the center of the beaker. Two students predict the final position of the block and draw the sketch at right.

Student 1: *Since this block is heavier than block B, it will not go up as high after it is released, as shown at right.*

Student 2: *Yes, I agree, the buoyant force is slightly less than the weight of this block, so it should come to rest a bit below the surface.*

Explain what is *wrong* with each statement and with the diagram.




Student drawing