Chapter 13

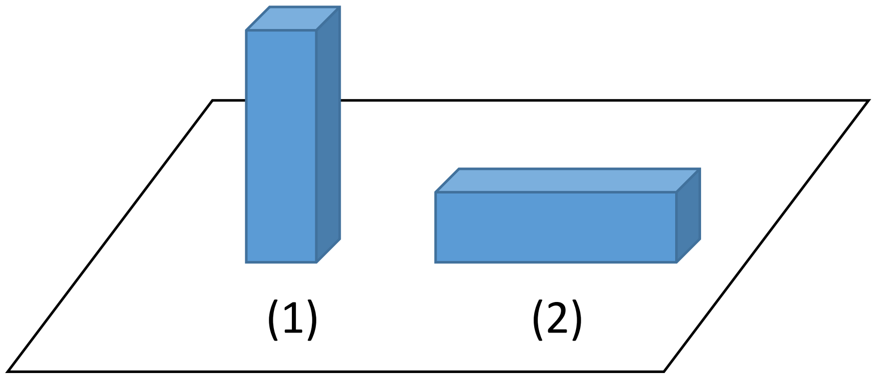
Liquids

Defining "Pressure"

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

Metric Units: 1 Pascal (Pa) = $1\,\frac{\text{Newton}}{\text{meter}^2}$

Consider two identical rectangular blocks (each of mass *m*) that are placed on the table as shown:



Question: Which exerts a greater *force* on the table?

Answer: Both the same. (Each has weight of *mg*.)

Question: Which exerts a greater *pressure* on the table?

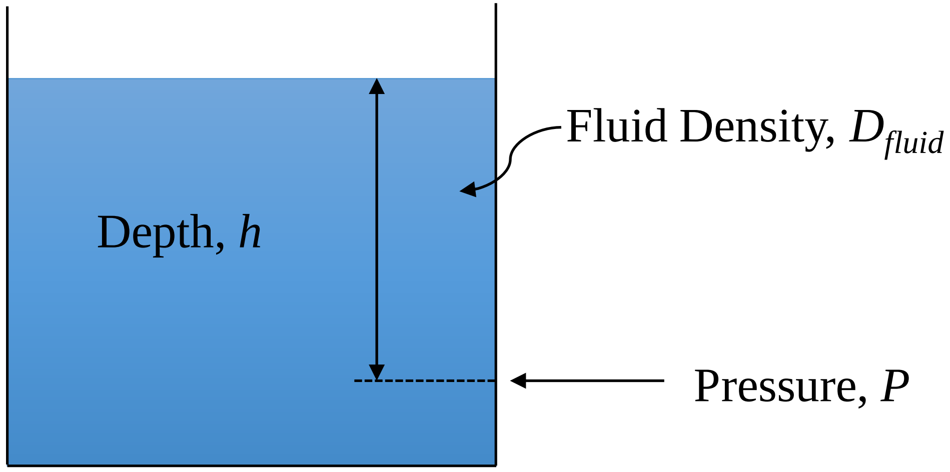
Answer: The block standing on its end (Block 1). Why?

Pressure in a (Static) Liquid

Liquid Pressure = Mass Density (of the liquid) x g x Depth (below surface)

That is, $P = D_{liq}gh$.

Pressure within a given liquid depends only on the depth below the surface.

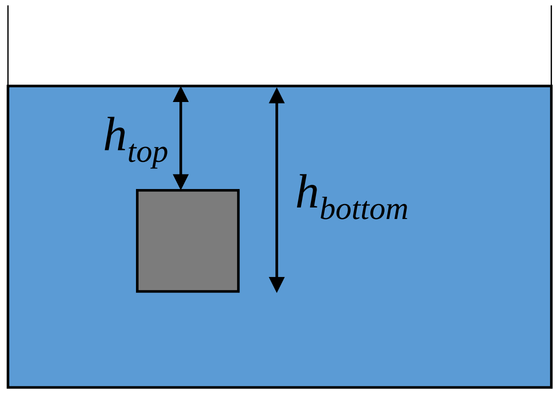


Question: Which has greater pressure at the bottom: the large shallow lake of the smaller deep pond?

Answer: The small deep pond due to its greater depth.

Buoyancy

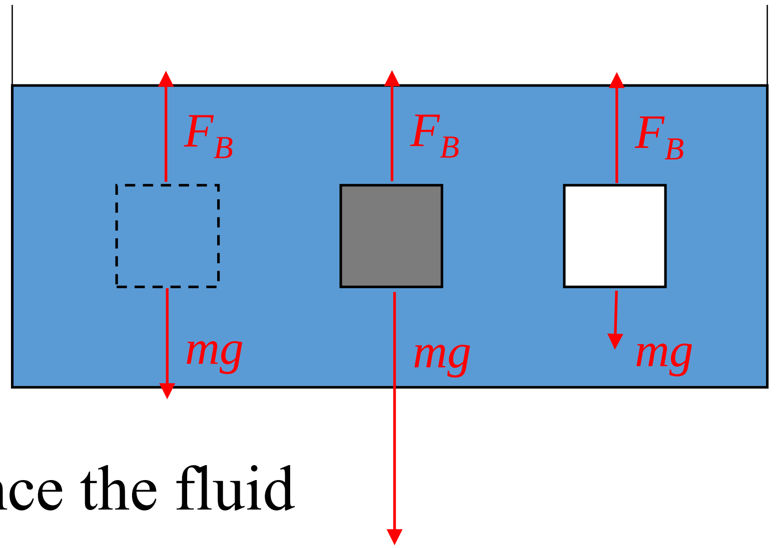
A heavy object submerged in water (or any fluid) is lighter than when the same object is not submerged. There seems to be some upward force acting on the object while under water. Once lifted above the surface, the lifting force required increases. Why?



Consider a metal cube that is held below the surface as shown. Note that the pressure is greater on the bottom face than the top face. (Recall the pressure within a liquid depends only on the depth.) Furthermore, since it's a cube, the area of each face is the same. Therefore, the downward force acting on the top face has a smaller magnitude than the magnitude of the upward force acting on the bottom face. As a result, the water Exerts a net upward force (called the buoyant force) on the cube.

Buoyancy & Archimedes' Principle

Consider the tank of (static) water below that has a "cube" of water selected as well as two other same sized cubes: one of metal and the other of Styrofoam.

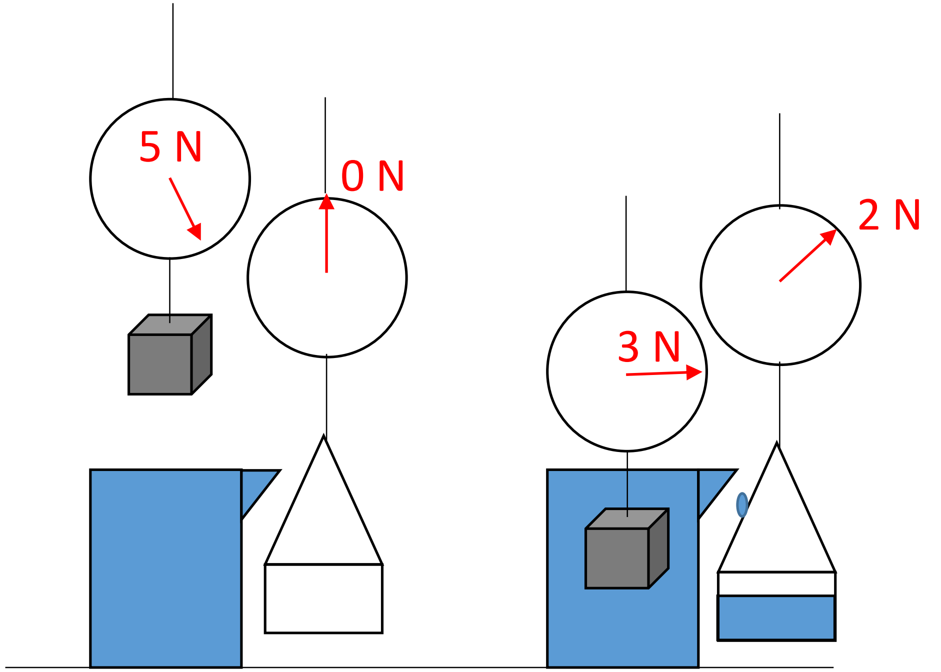


The imaginary "cube" of water neither sinks nor floats since the fluid is static. Therefore the weight (mg)of that "cube" is balanced by the buoyant force (F_B) that the rest of the water exerts on it. A same sized cube of metal experiences the same F_B as does a same sized cube of Styrofoam since they each displace the same amount of fluid.
But the weight of the metal cube is greater than the same volume of water and will sink, whereas the Styrofoam cube has a much smaller weight that the same volume of water, so the Styrofoam will be buoyed to the surface. That is, it will float.

Archimedes' Principle

"An immersed object is buoyed up by a force equal to the weight of the fluid it displaces."

Example:
If an object immersed into a fluid displaces, say 0.2 kg of that fluid, then the magnitude of the upward buoyant force on the object is $F_B = 2$ N. The object will be 2 N lighter than when it is not immersed in the fluid.



Note that a fully submerged object displaces a *volume* of fluid equal to its own volume.

Floating & Sinking

Whether an object sinks or floats in a particular fluid depends whether the weight of the object is greater or less than the weight of an equal volume of fluid displaced.

In other words, if the density of an object is…

1) greater than that of the fluid, the object will sink.

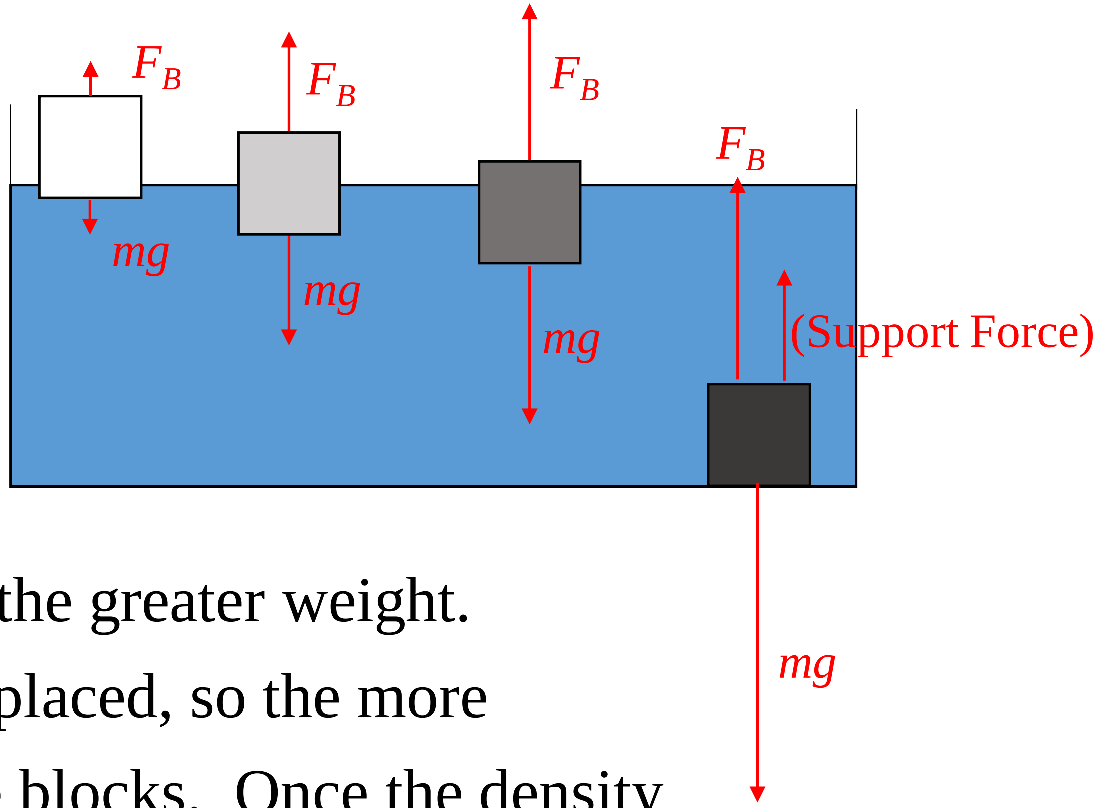
2) less than that of the fluid, the object will float.

3) the same as that of the fluid, the object will neither sink nor float.

In the earlier example, the metal cube sinks (more dense than water) and the Styrofoam floats (less dense than water).

The Principle of Flotation

“A floating object displaces a weight of fluid equal to its own weight.”



Example:

Each of the four cubes have the same volume, but increase in density from left to right. The blocks with the larger density have more mass and therefore weight more. In order to float, there has to be a greater buoyant force to counter the greater weight. a greater buoyant force requires more fluid be displaced, so the more dense blocks do not float as high as the less dense blocks. Once the density of the block exceeds that of the fluid, the buoyant force can no longer support the object and the object will sink until it reaches the bottom of the tank.

Special Note!

Archimedes' principle applies whether the object is wholly or partially submerged in the fluid. That is, the magnitude of the upward buoyant force is always equal to the weight of the displaced by the submerged portion of the object. Mathematically,

$$F_B = m_{fluid}g = (D_{fluid}V_{submerged})g, \text{ since } D = m/V.$$

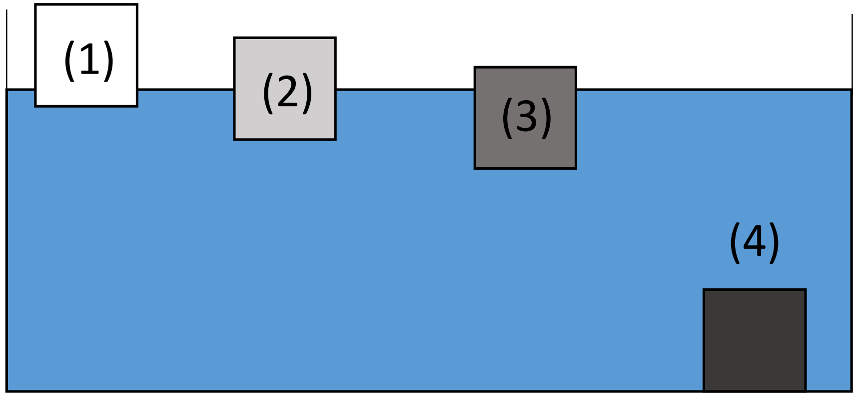
The Principle of Flotation only applies to floating objects. If an object floats, then

$$F_B = m_{object}g = (D_{object}V_{object})g.$$

So, for a floating object…

$(D_{fluid}V_{submerged})g = (D_{object}V_{object})g$ and therefore $\frac{D_{object}}{D_{fluid}} = \frac{V_{fluid}}{V_{object}}$

That is, the ratio of the density of the object to that of the fluid is equal to the ratio of the submerged volume of the object to that of the entire object.



Object 1: about 10% submerged so it has about 10% the density of the fluid.

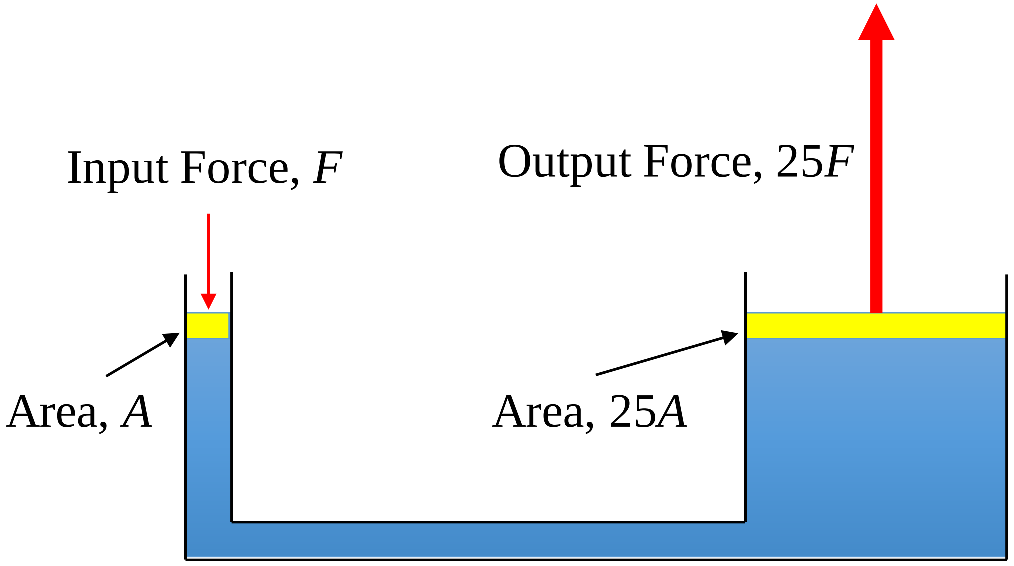
Object 2: about 50% submerged so it has about 50% the density of the fluid.

Object 3: about 75% submerged so it has about 75% the density of the fluid.

Object 4 sinks so its density is greater than that of the fluid. (The flotation principle does not apply.)

Pascal's Principle & The Hydraulic Lever

"A change in pressure at any point in an enclosed fluid is transmitted undiminished to all parts of the fluid (and to the walls of the container).



Consider the U-shaped container fitted with (assumed frictionless) pistons where one side has a larger area than the other. A small weight placed on the small piston produces an additional pressure on that area. This change in pressure is transmitted undiminished to all part of the fluid and to the large piston. With the same pressure on the larger piston, the force on the larger piston must be greater. So, the small force is amplified to lift the heavy load.

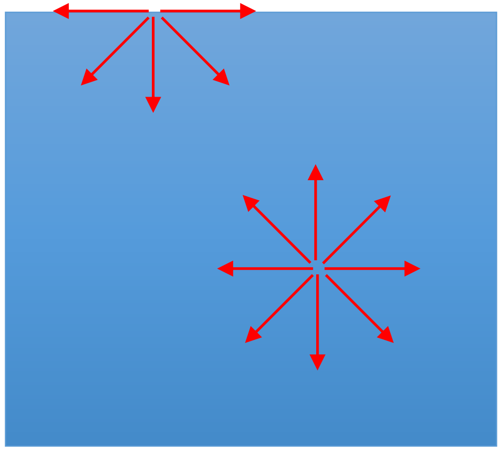
Surface Tension…

…is the name of the phenomenon in which attractive molecular forces between the liquid molecules, (called *cohesion*), cause the liquid surface to resist being stretched.

It accounts for the spherical shape of liquid drops.

Below the surface, each water molecule is pulled in every direction by the cohesive forces by neighboring water molecules.

For molecules at the surface, there are only cohesive forces tending to pull the molecule downward into the liquid.



Capillarity…

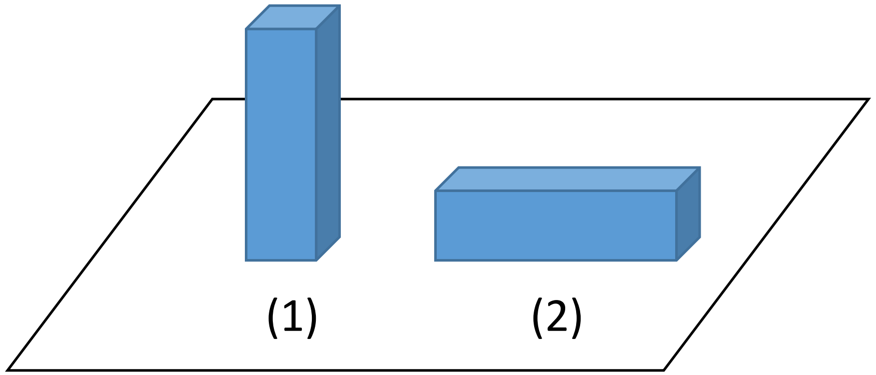
…is the name given to the phenomenon is which water gets drawn up into very tiny tubes. (You have seen this if you have ever witnessed a paper towel soaking up a liquid.)

The reason has to do with two completing intermolecular forces:

Cohesion: the attractive force between "like" molecules, and

Adhesion: the attractive force between "unlike" molecules.

In this case of water in glass, the water molecules prefer to stick to glass than to themselves, so the adhesion between the water and the glass is greater than the cohesion of the water with itself.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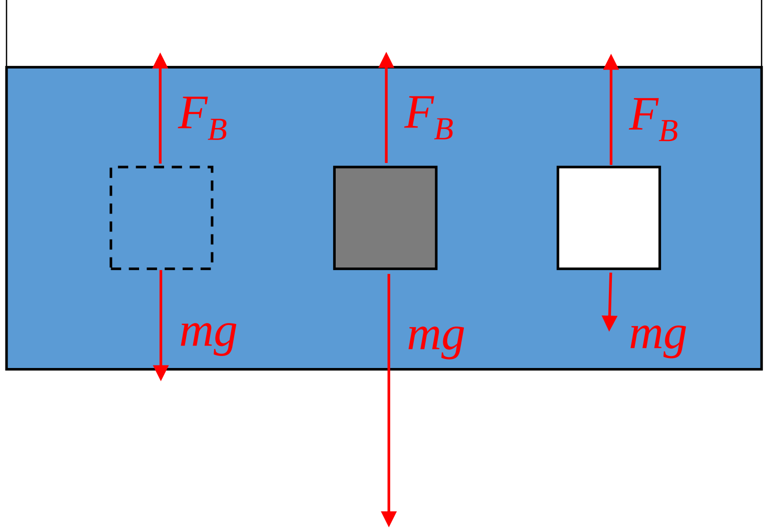
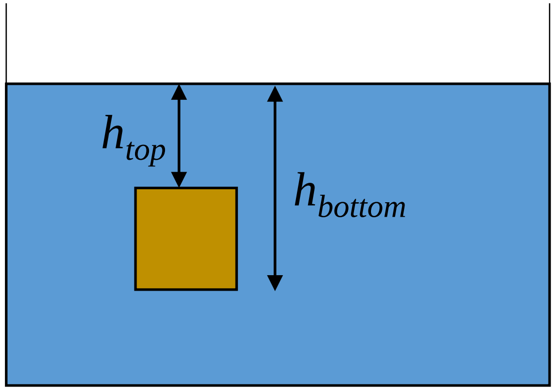
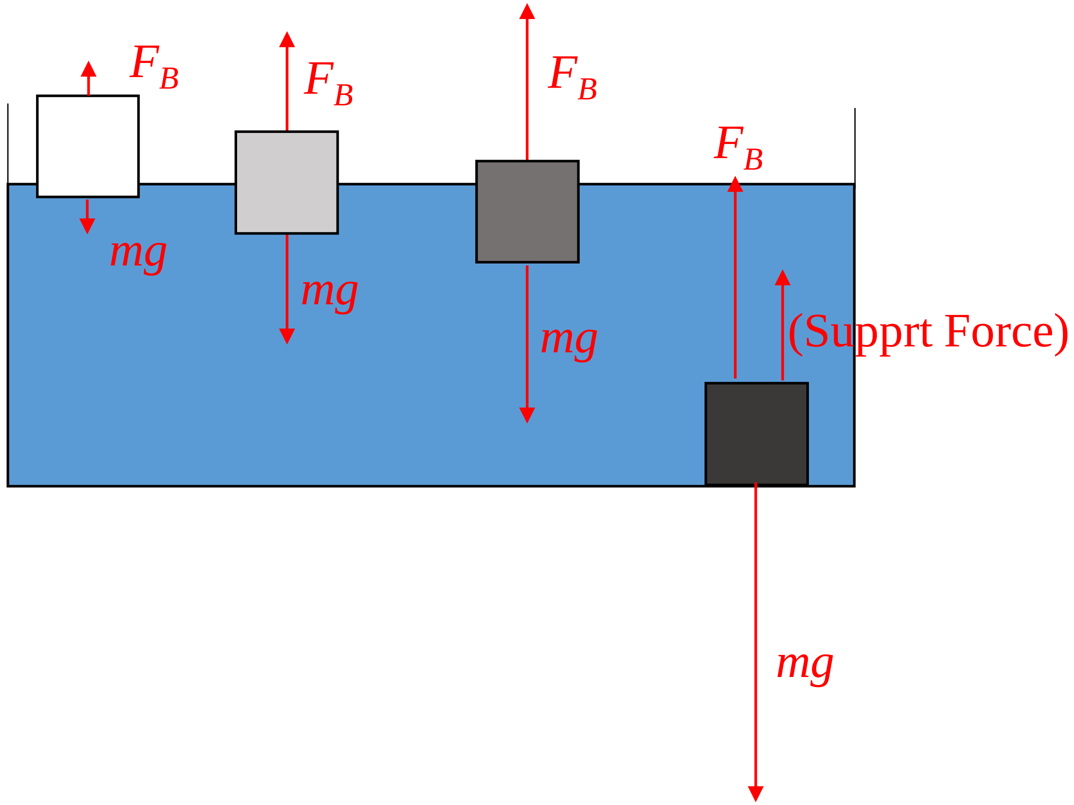

F_B
F_B
F_B
mg
mg
mg


h_{top}
h_{bottom}


F_B
F_B
F_B
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mg
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(Supprt Force)
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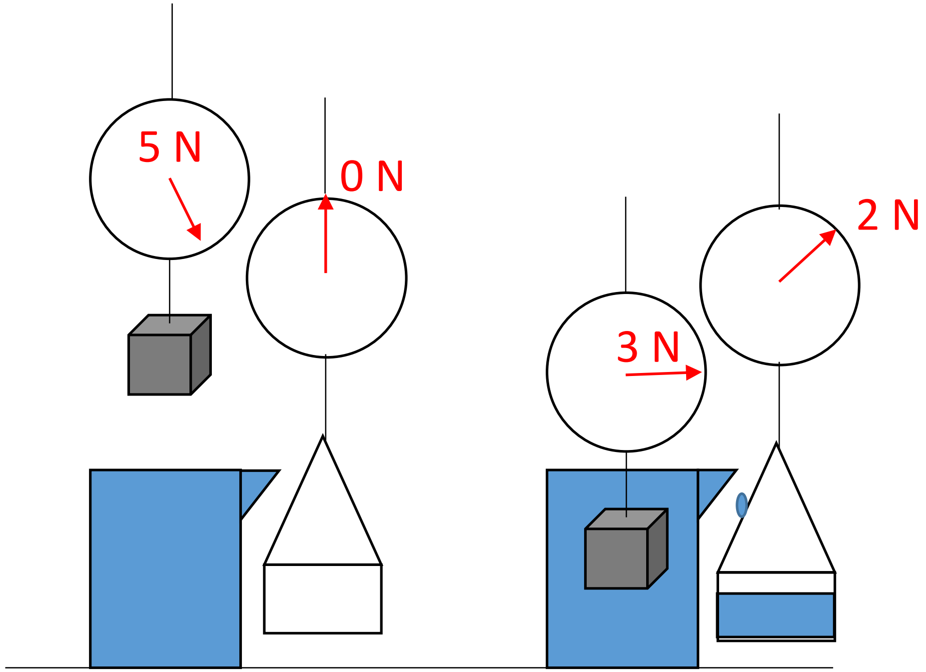
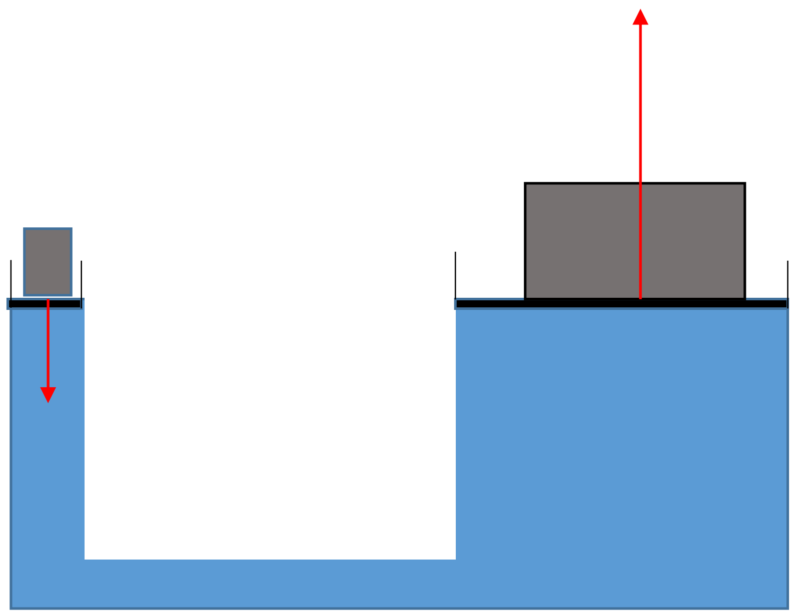
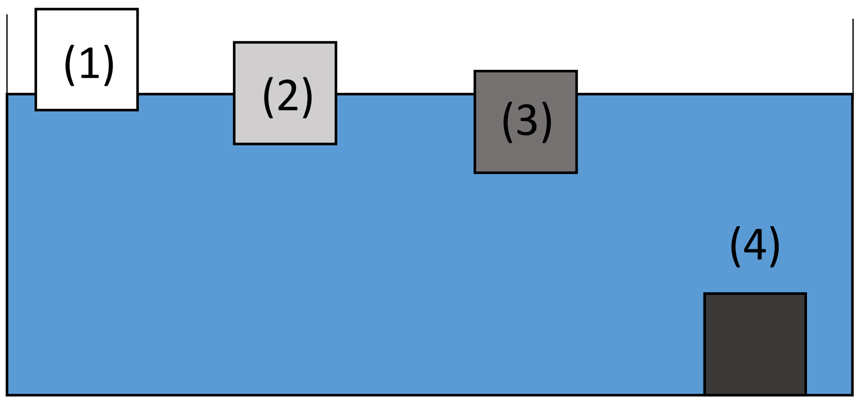

5 N
0 N
3 N
2 N

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