Image from https://w-dog.net/wallpaper/mclaren-f1-gtr-longtail-1997-mclaren-f1-supercar-racing-car-rear-view-spoiler-wing-rostrum-background/id/213090/

2304153: PHYSICS ENGS

Update: Oct 31, 2022

Fluid mechanics

- Pressure
- Variation of pressure with depth
- Pressure measurements
- Buoyant forces and archimedes's principle
- Fluid dynamics
- Bernoulli's equation
- Other applications of fluid dynamics

N. Srimanobhas (Norraphat.Srimanobhas@cern.ch)

https://twiki.cern.ch/twiki/bin/view/Main/PhatSrimanobhasTeaching

Fluids

A fluid is a collection of molecules that are randomly arranged and held together by weak cohesive forces and by forces exerted by the walls of a container. Both liquids and gases are fluids.

REALLY?

The Claim: Drink Plenty of Fluids to Beat a Cold

By ANAHAD O'CONNOR
Published: January 10, 2011

THE FACTS

Enlarge This Image

Christoph Niemann

The advice for conquering a cold is time-honored: Get plenty of rest and drink lots of fluids.

While it's hard to argue against getting proper rest, some scientists suspect that loading up on liquid — that is, beyond the normal amount required in a day — may not do much good.

Theoretically, taking in extra beverages like water and juice

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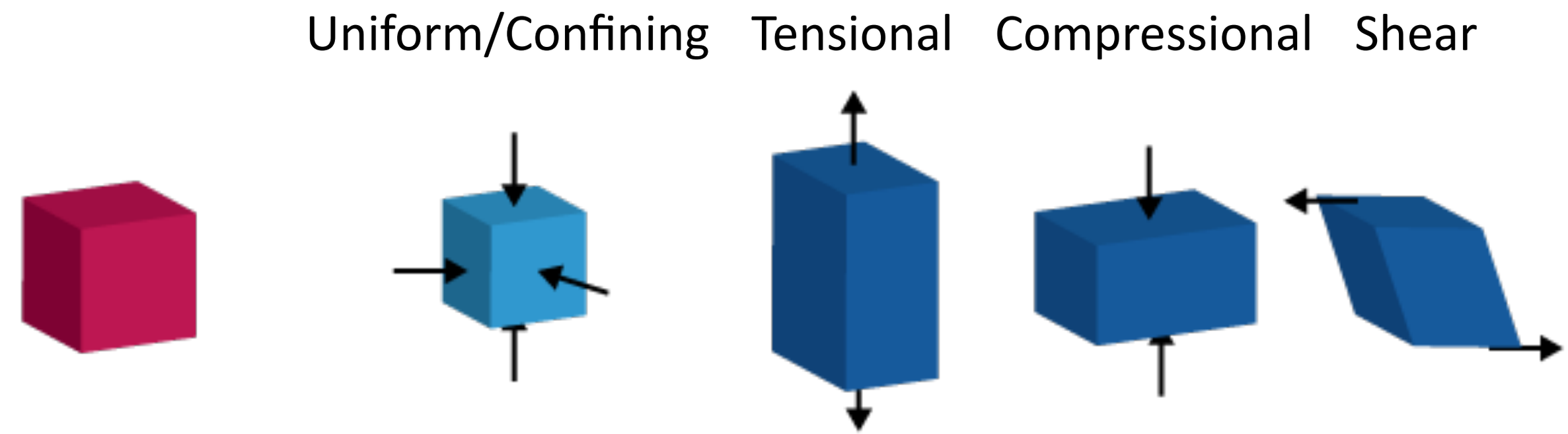
http://www.nytimes.com/2011/01/11/health/11really.html

Fluids

Fluids do not sustain shearing stresses or tensile stresses; therefore, the only stress that can be exerted on an object submerged in a static fluid is one that tends to compress the object from all sides.

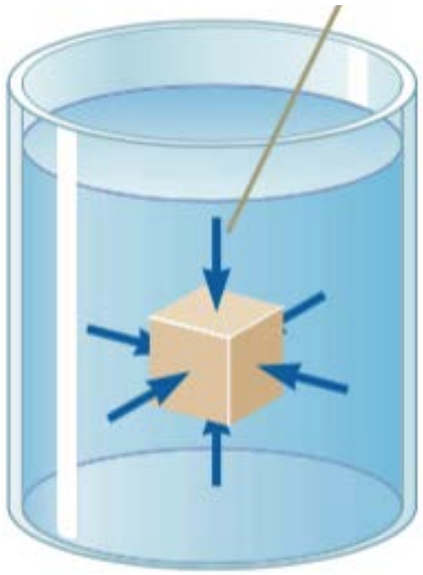


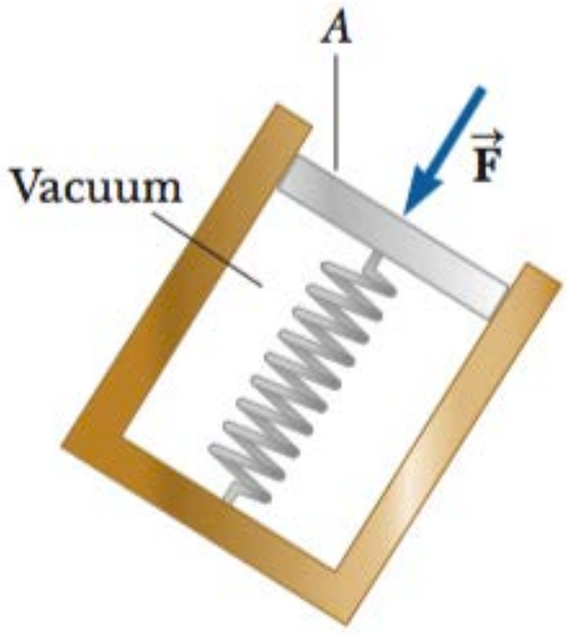
Pressure

Density = mass per unit volume (kg/m³)

$$\rho = \lim_{\Delta V \to 0} \frac{\Delta m}{\Delta V}$$

Pressure (symbol P) is the force applied perpendicular to the surface of an object per unit area over which that force is distributed. Pressure is a scalar quantity because it is proportional to the magnitude of the force on the piston.





The units of pressure are newtons per square meter (N/m²) in the SI system. Another name for the SI unit of pressure is the pascal (Pa):

$$P \equiv \frac{F}{A}$$

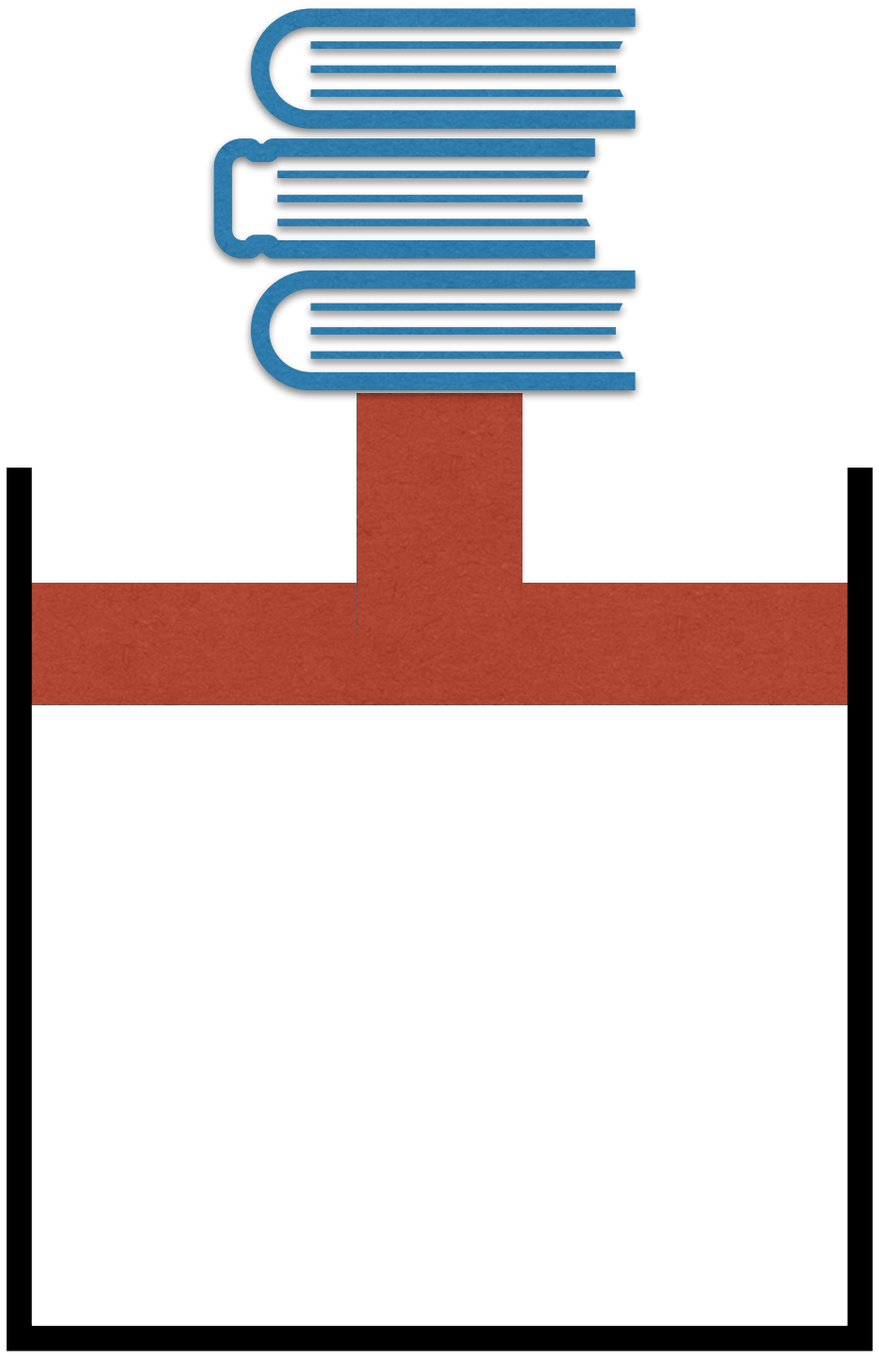
Compressibility

Compressibility is a measure of the relative volume change of a solid or a fluid in response to a pressure change.

- **Compressible fluid**: Gas
- **Incompressible fluid**: incompressible flow (isochoric flow) refers to a flow in which the material density is constant within a fluid parcel—an infinitesimal volume that moves with the flow velocity. Ex, most of liquid.

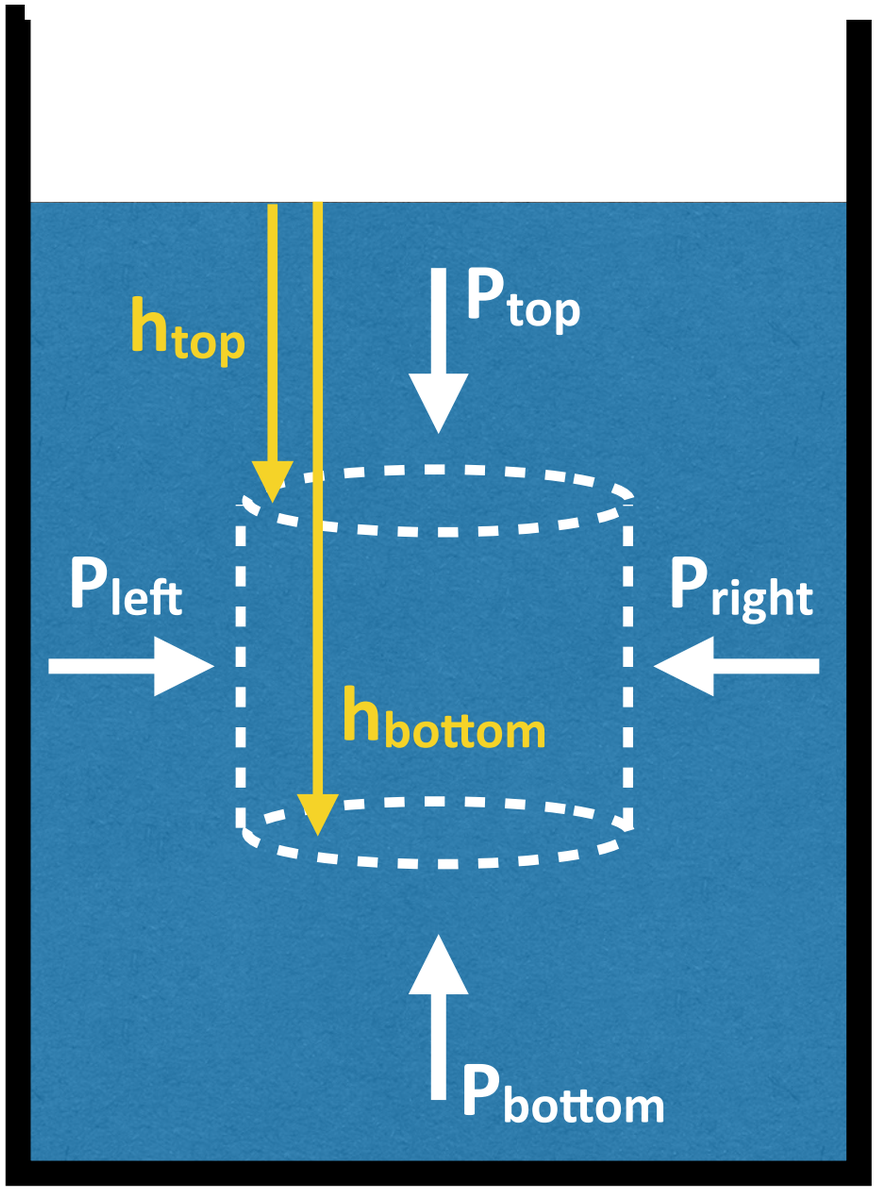
Compressible fluid is matter that can be compressed with the application of an external pressure	Incompressible fluid is matter that cannot be compressed with the application of an external pressure
Volume can be reduced with the application of a pressure on the fluid	Volume cannot be reduced with the application of a pressure on the fluid
Density can be changed with the application of a pressure on the fluid	Density cannot be changed with the application of a pressure on the fluid
Value of Mach number should be greater than 0.3	Value of Mach number should be less than 0.3

Types of pressure



Fluid statics

Fluid statics is the part of fluid mechanics that deals with fluids when there is no relative motion between the fluid particles. Typically this includes two situations: when the fluid is at rest and when it moves like a rigid solid.



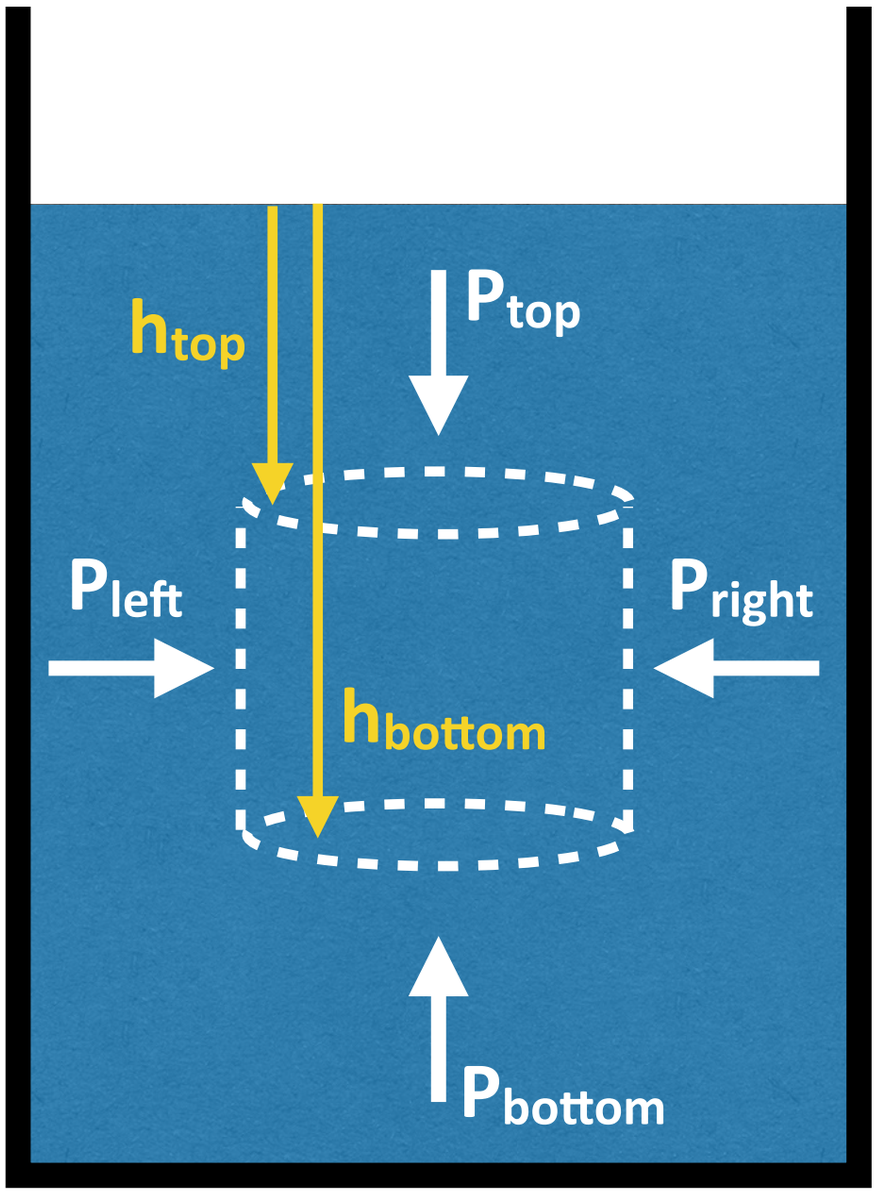
Liquid with density ρ

Consider left-right:

Consider top-bottom:

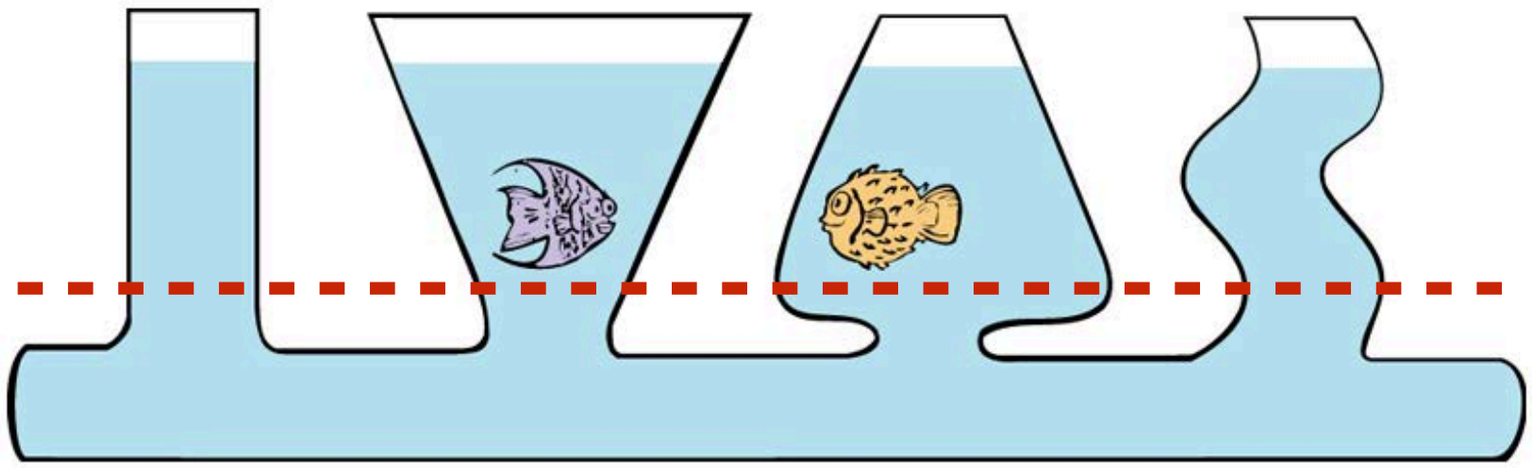
Variation of pressure with depth

From $P_{\text{bottom}} = P_{\text{top}} + \rho g(h_{\text{bottom}} - h_{\text{top}})$, we can get



Liquid with density ρ

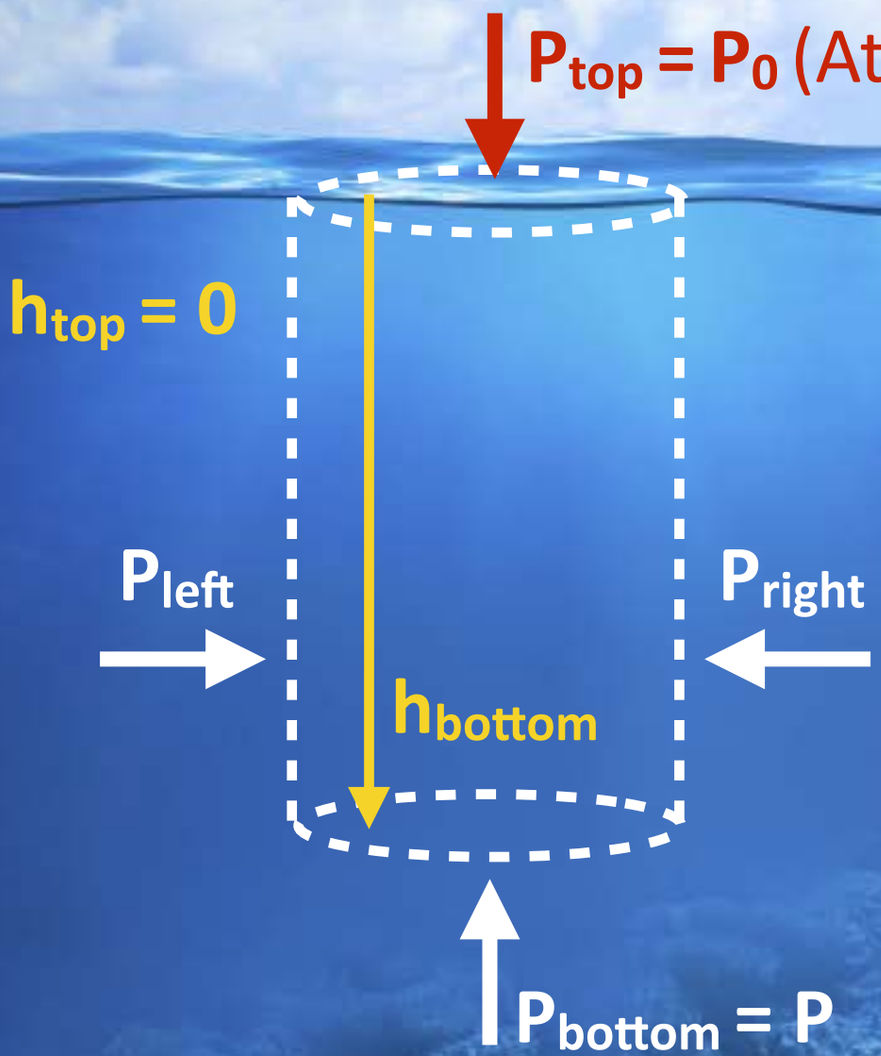
(1) Pressure and shape of container:



http://w3.shorecrest.org/~Lisa_Peck/Physics/syllabus/phases/liquids/ch19liquid_images/ch19_images.htm

Variation of pressure with depth

(2) How does pressure change with ocean depth?



Variation of pressure with depth

$P_{top} = 0$ (Empty space)

(3) Estimate the height of the Earth's atmosphere

$h_{top} = 0$

h_{bottom} = Height of the Earth's atmosphere

$P_{bottom} = P_0$

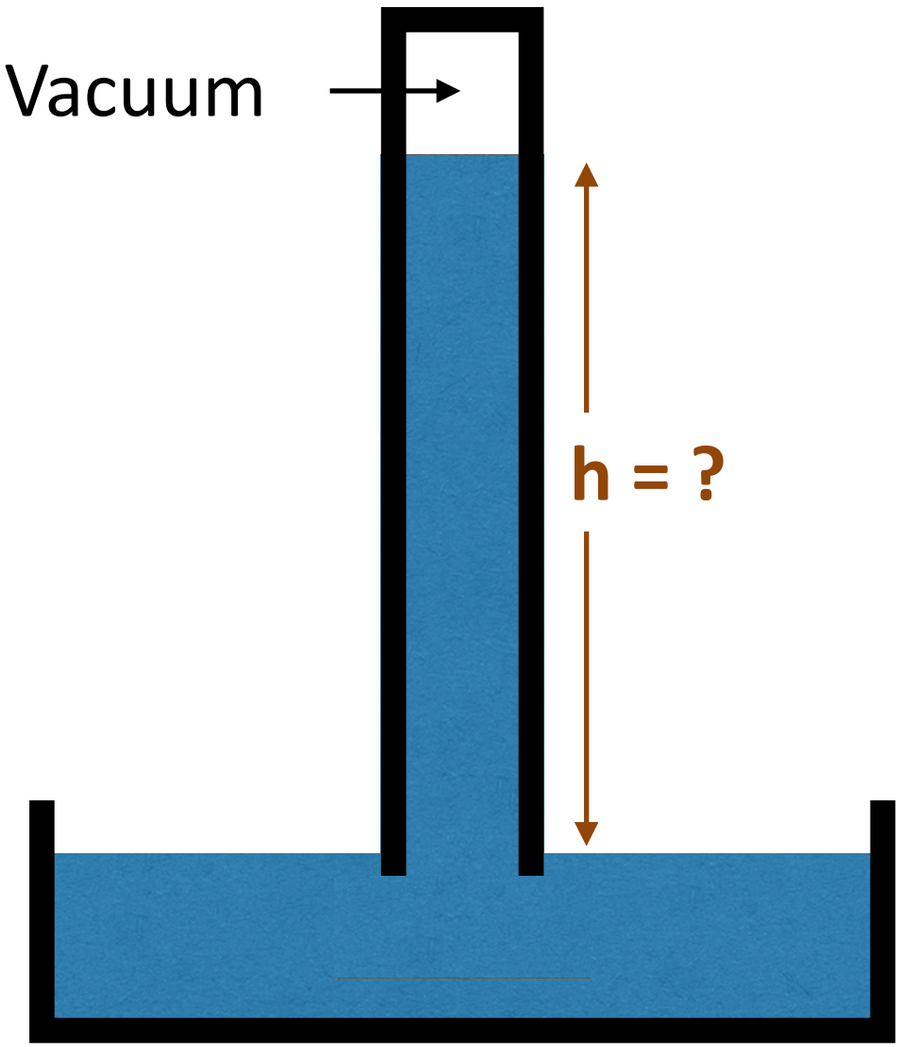
(Atmospheric pressure)

Example- I

A container is filled to a depth of 20.0 cm with water. On top of the water floats a 30.0-cm-thick layer of oil with specific gravity 0.700. What is the absolute pressure at the bottom of the container?

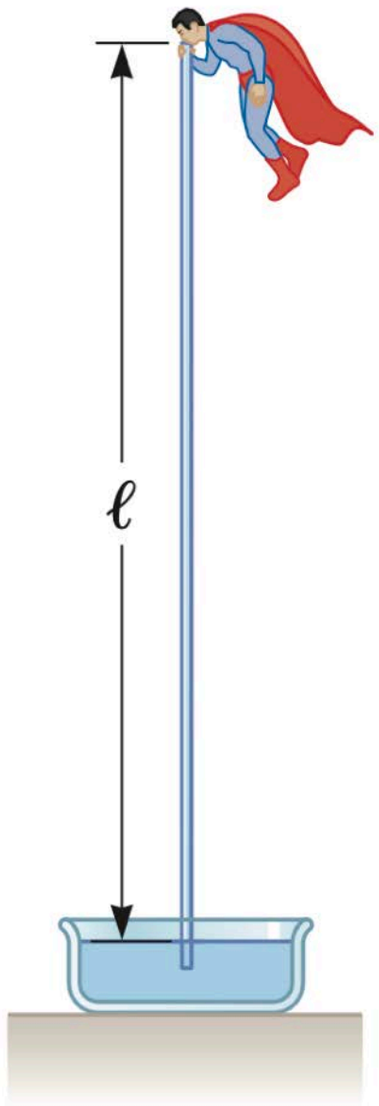
Barometer

A barometer is a scientific instrument that is used to measure air pressure in a certain environment. Pressure tendency can forecast short term changes in the weather

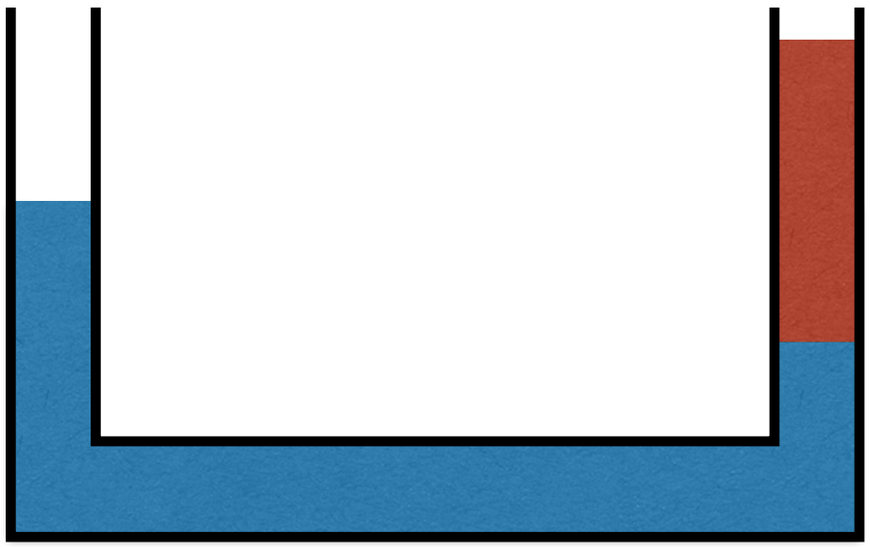


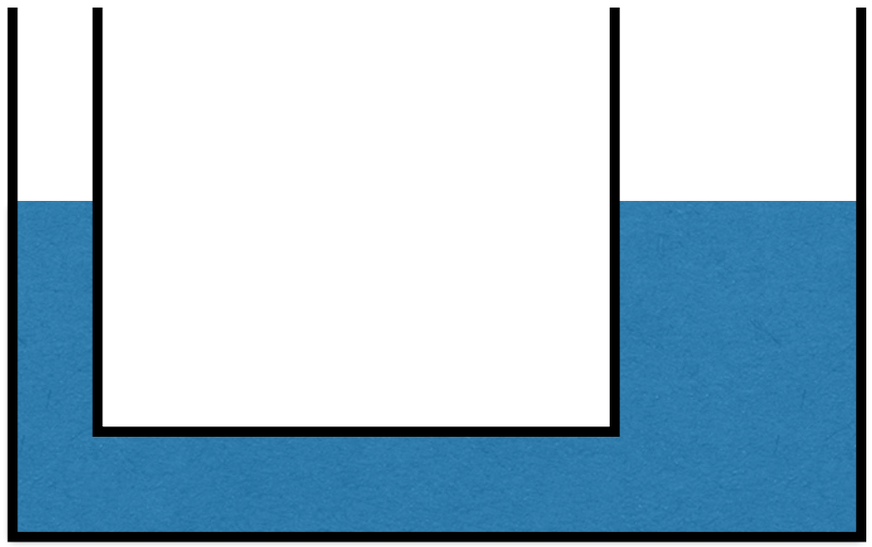
Example-2

Superman attempts to drink cold water through a straw of length $l = 12.0$ m. The walls of the tubular straw are very strong and do not collapse. With his great strength, he achieves maximum possible suction and enjoys drinking the cold water.



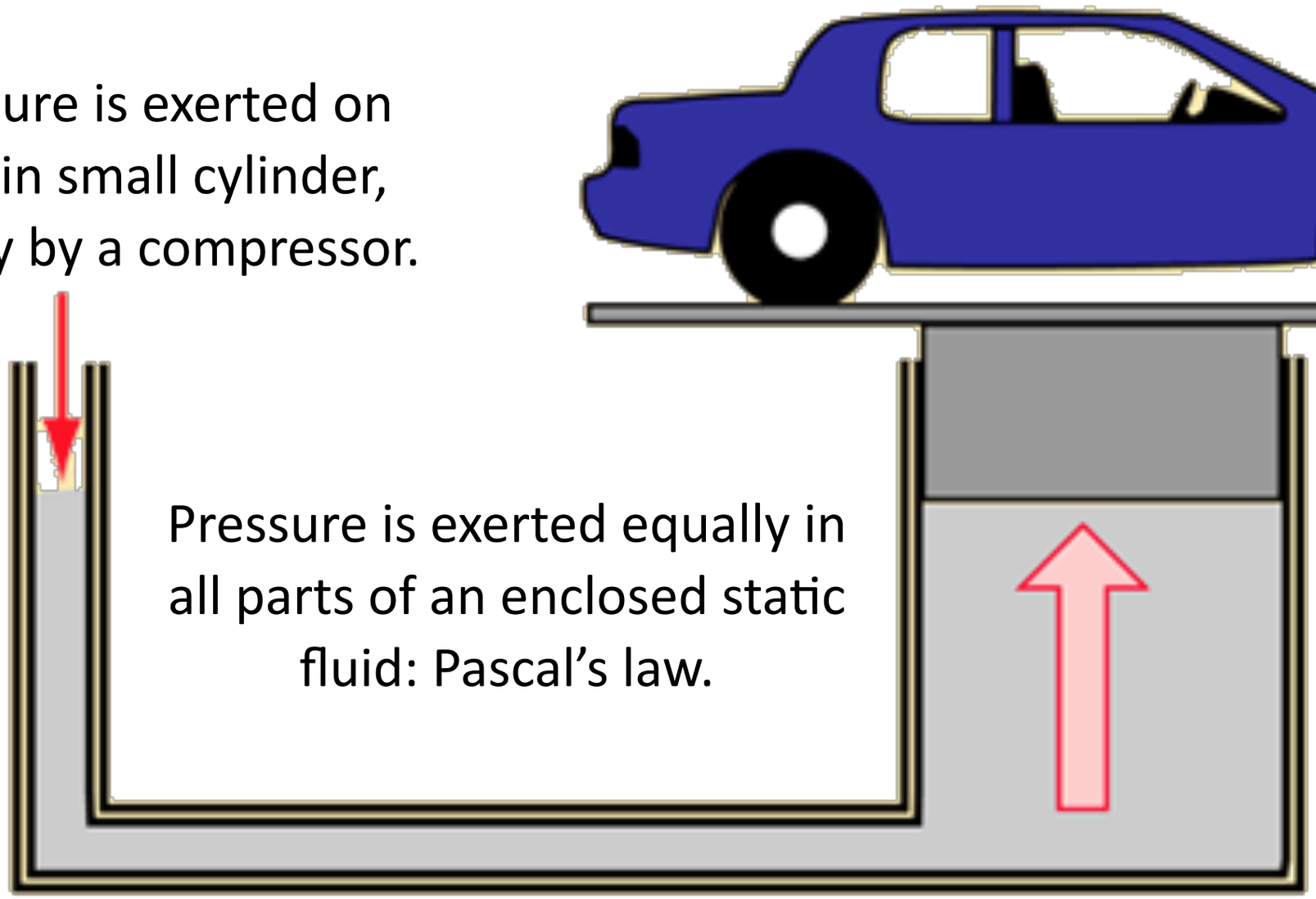
Example-3





Hydraulic lift

Pressure is exerted on fluid in small cylinder, usually by a compressor.



Though the pressure is the same, it is exerted over a much larger area, giving a multiplication of force that lifts the car.

The force in the small cylinder must be exerted over a much larger distance. **A small force exerted over a large distance is traded for a larger force over a small distance.**

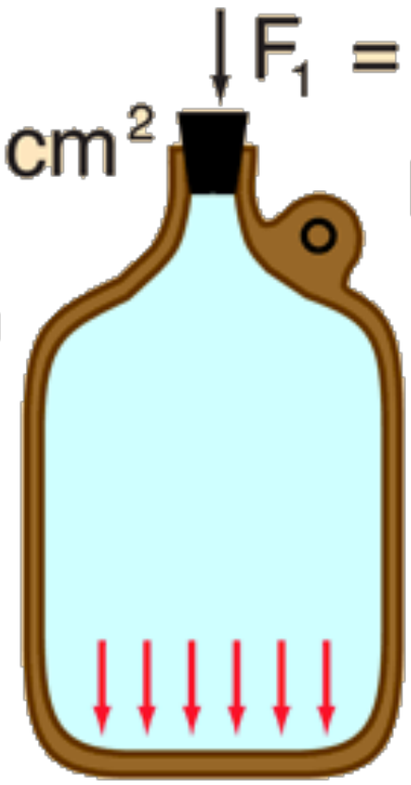
http://hyperphysics.phy-astr.gsu.edu/hbase/pasc.html

Pascal's law

http://hyperphysics.phy-astr.gsu.edu/hbase/pasc.html

Blaise Pascal
(1623 - 1662)

A change in the pressure applied to an enclosed fluid is transmitted undiminished to every portion of the fluid and to the wall of the containing vessel



$F_1 = 10$ N Applied force to the stopper

$A_1 = 5\ cm^2$

$P_1 = \frac{10\ N}{5\ cm^2} = 2\ N/cm^2$

Like a liquid lever, changing areas in an enclosed fluid permit multiplication of force

Pressure is transmitted undiminished in an enclosed static fluid.

$F_2 = P_2 A_2 = (2 N/cm^2)(500\ cm^2)$

$= 1000$ N!! plus the force from the weight of the liquid.

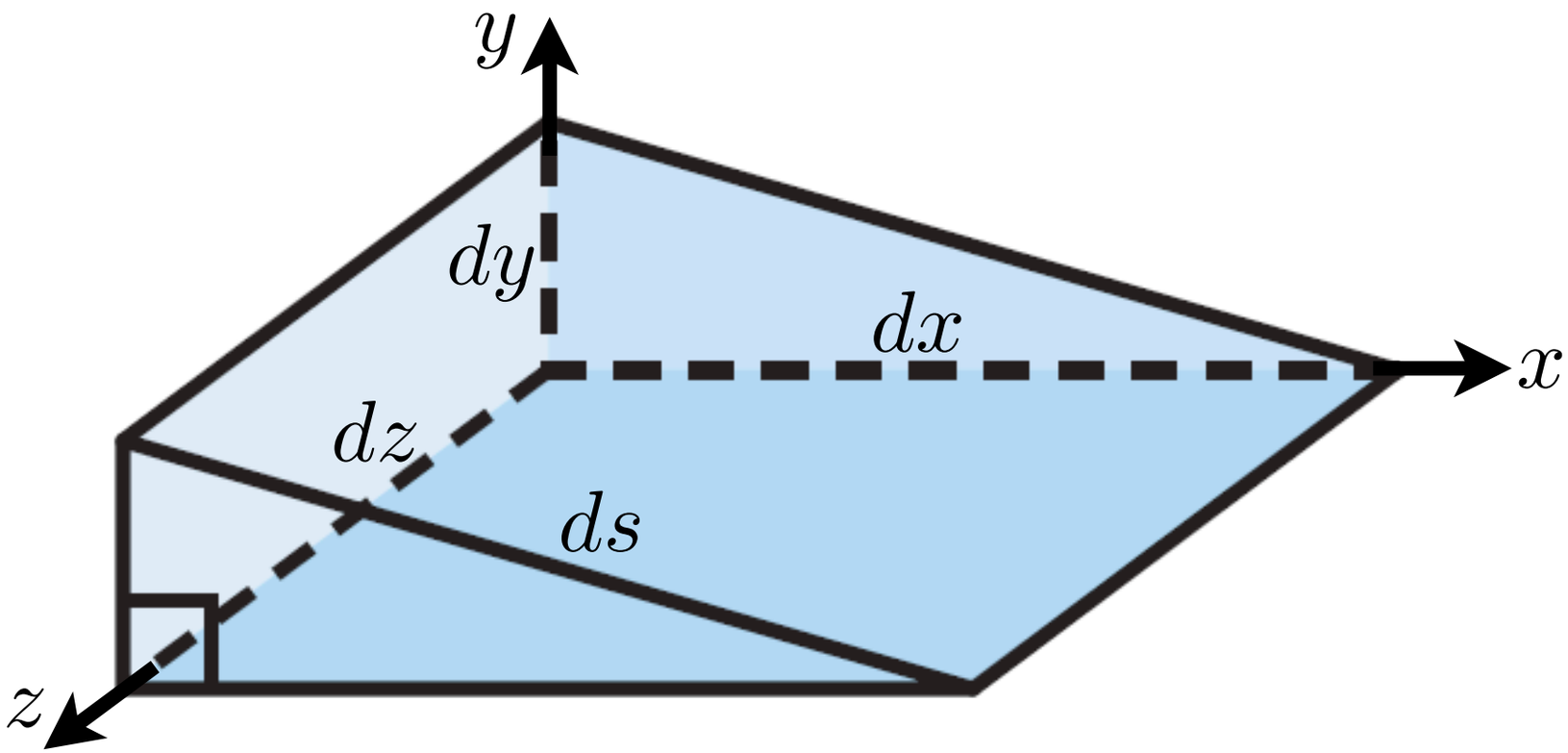
Resulting force on bottom of jug.

$A_2 = 500\ cm^2$

$P_2 = P_1 + \rho g h$ Static fluid pressure

http://hyperphysics.phy-astr.gsu.edu/hbase/pasc.html

Pascal's law

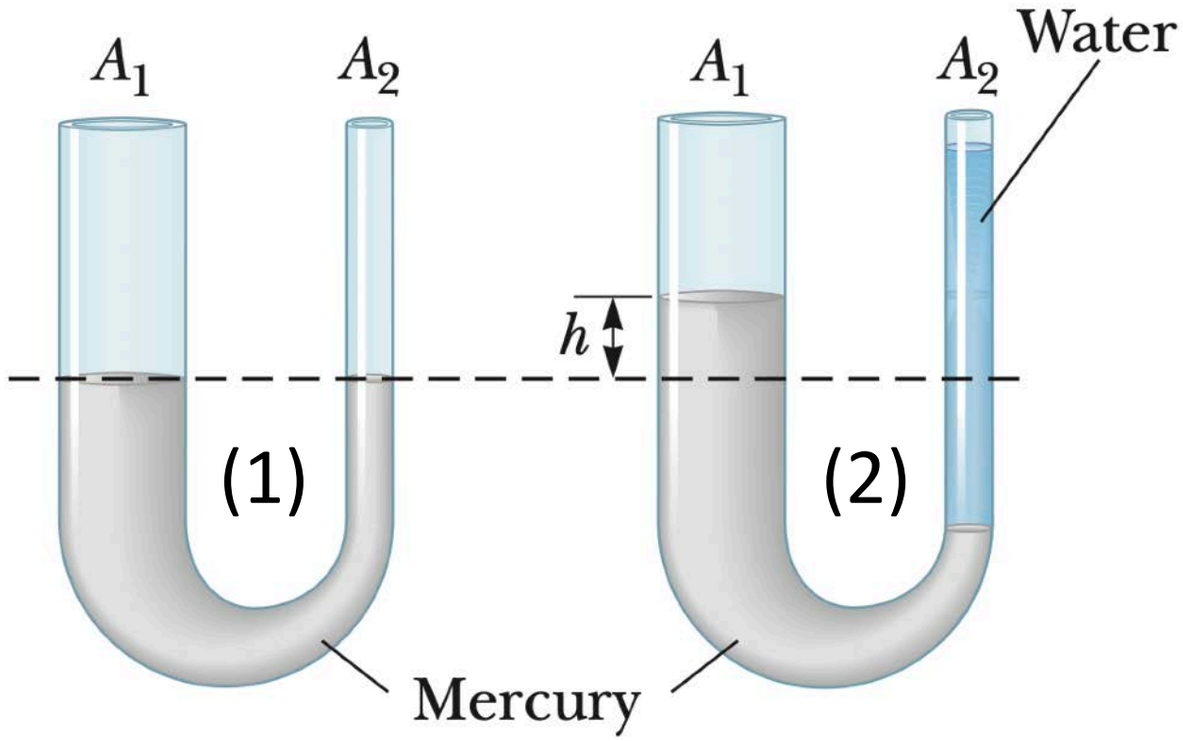


Example-4

Mercury is poured into a U-tube as shown in the Figure (1). The left arm of the tube has cross-sectional area A_1 of 10.0 cm², and the right arm has a cross- sectional area A_2 of 5.00 cm². One hundred grams of water are then poured into the right arm as shown in Figure (2).

(a) Determine the length of the water column in the right arm of the U-tube.

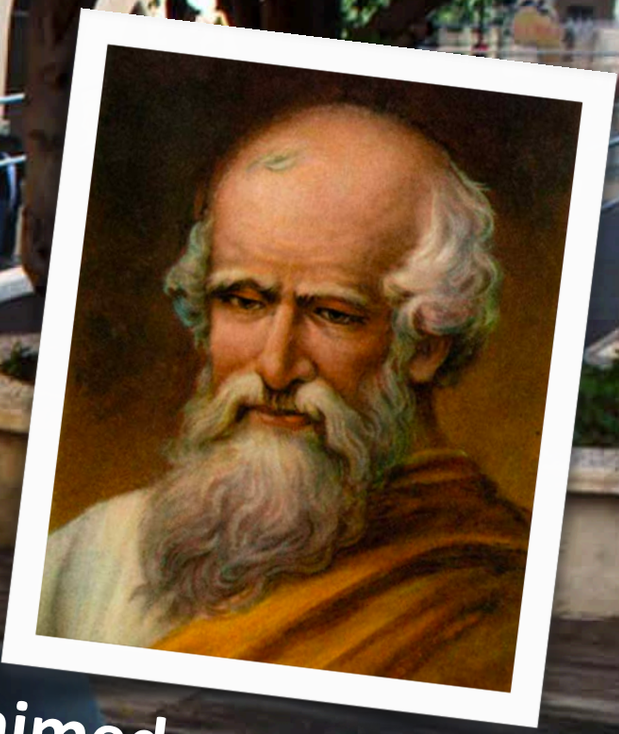
(b) Given that the density of mercury is 13.6 g/cm3, what distance h does the mercury rise in the left arm?



Example-4

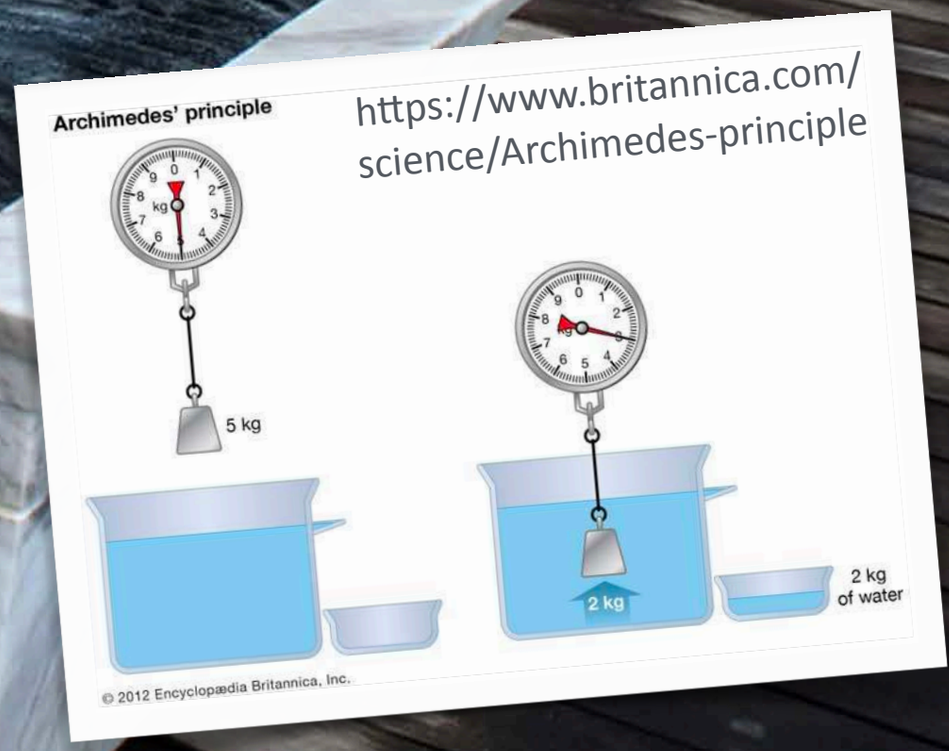
Why do deep-sea fish not get crushed by pressure on the sea floor?

Archimedes's principle



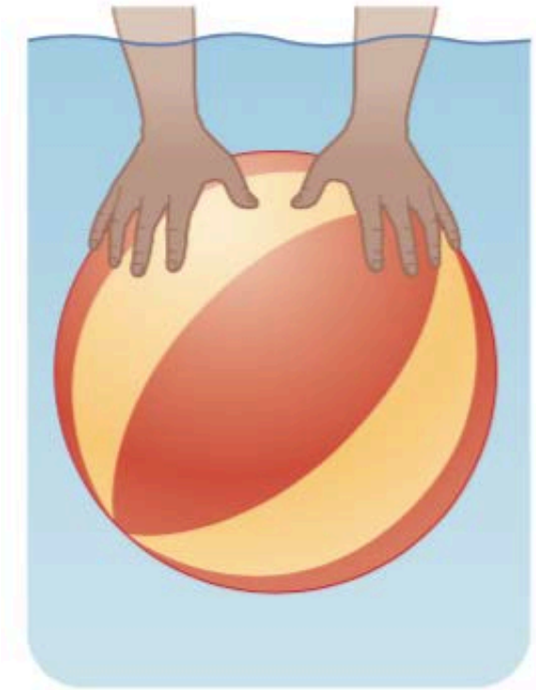
Archimedes of Syracuse
(c. 287 – c. 212 BC)

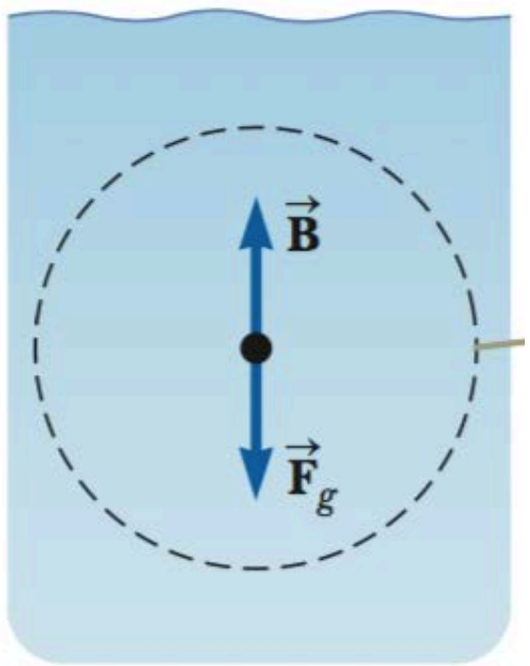
The buoyant force on a submerged object is equal to the weight of the fluid displaced.



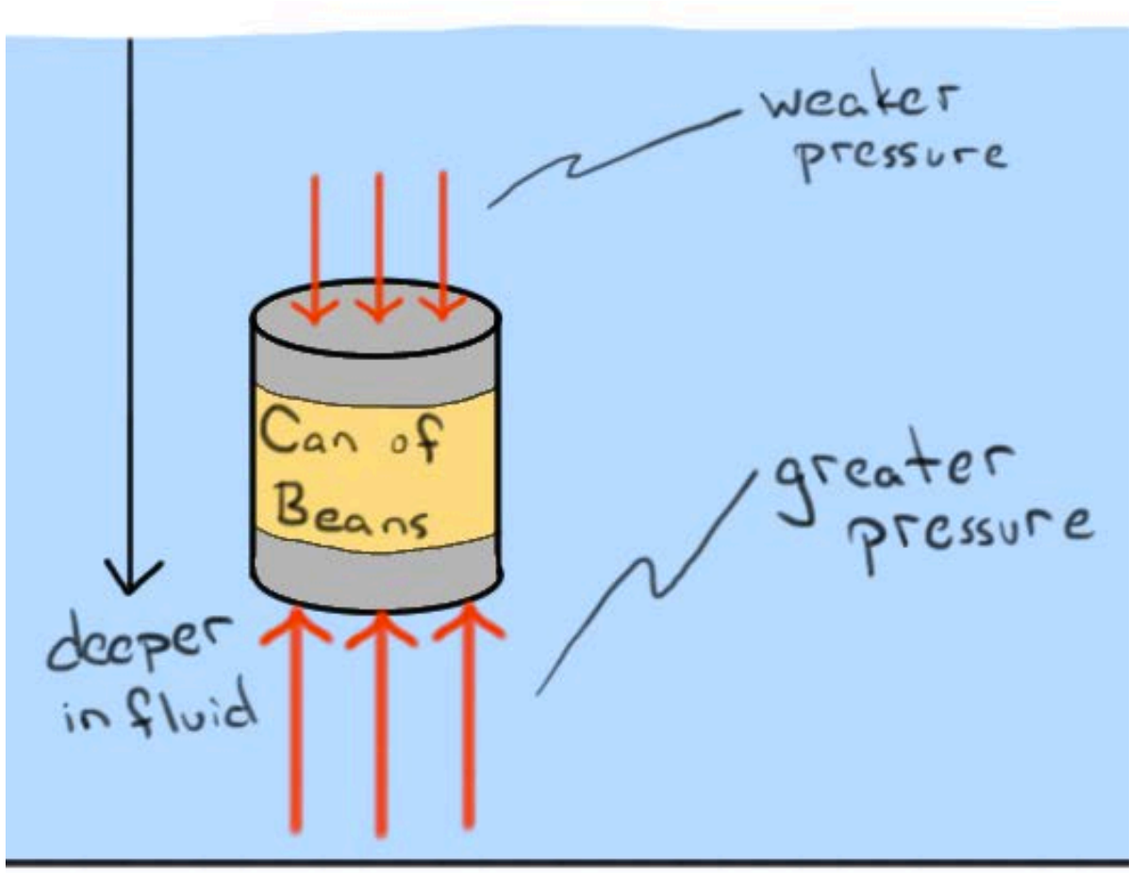
https://www.livescience.com/58839-archimedes-principle.html

Archimedes's principle



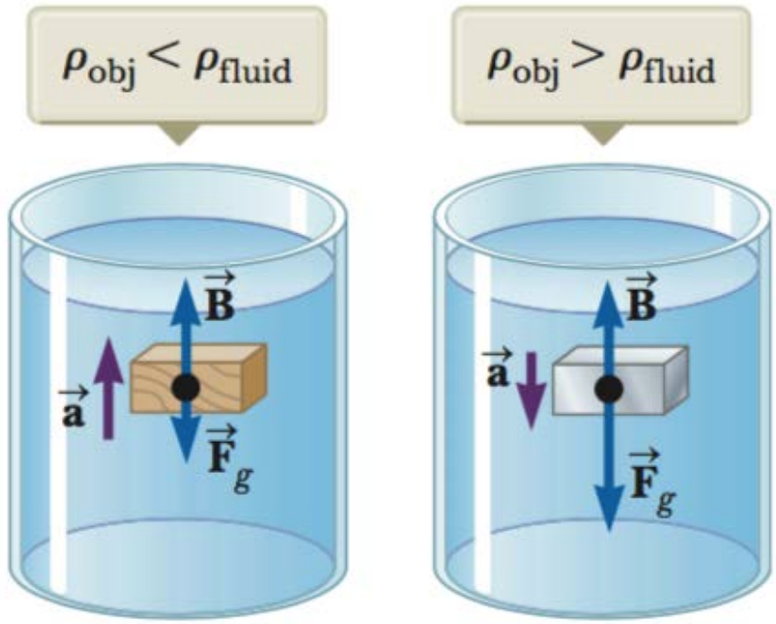


The buoyant force $\overrightarrow{B}$ on a ball that replaces this parcel of water is exactly the same as the buoyant force on the parcel.

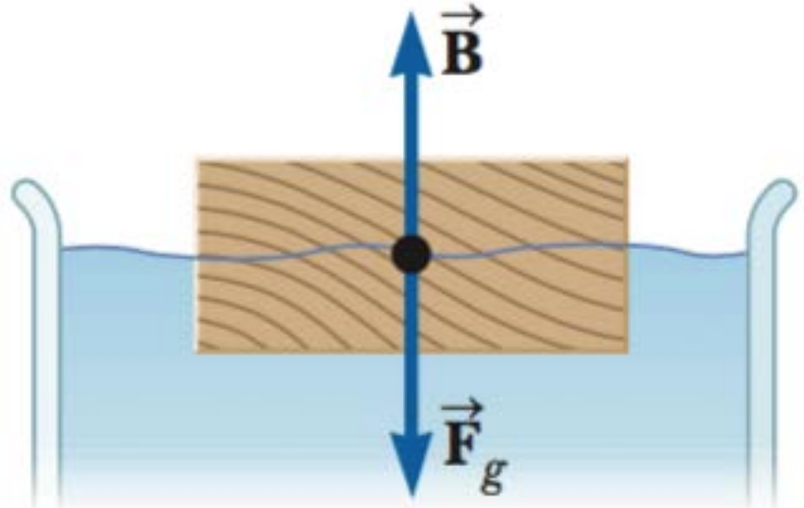


Archimedes's principle

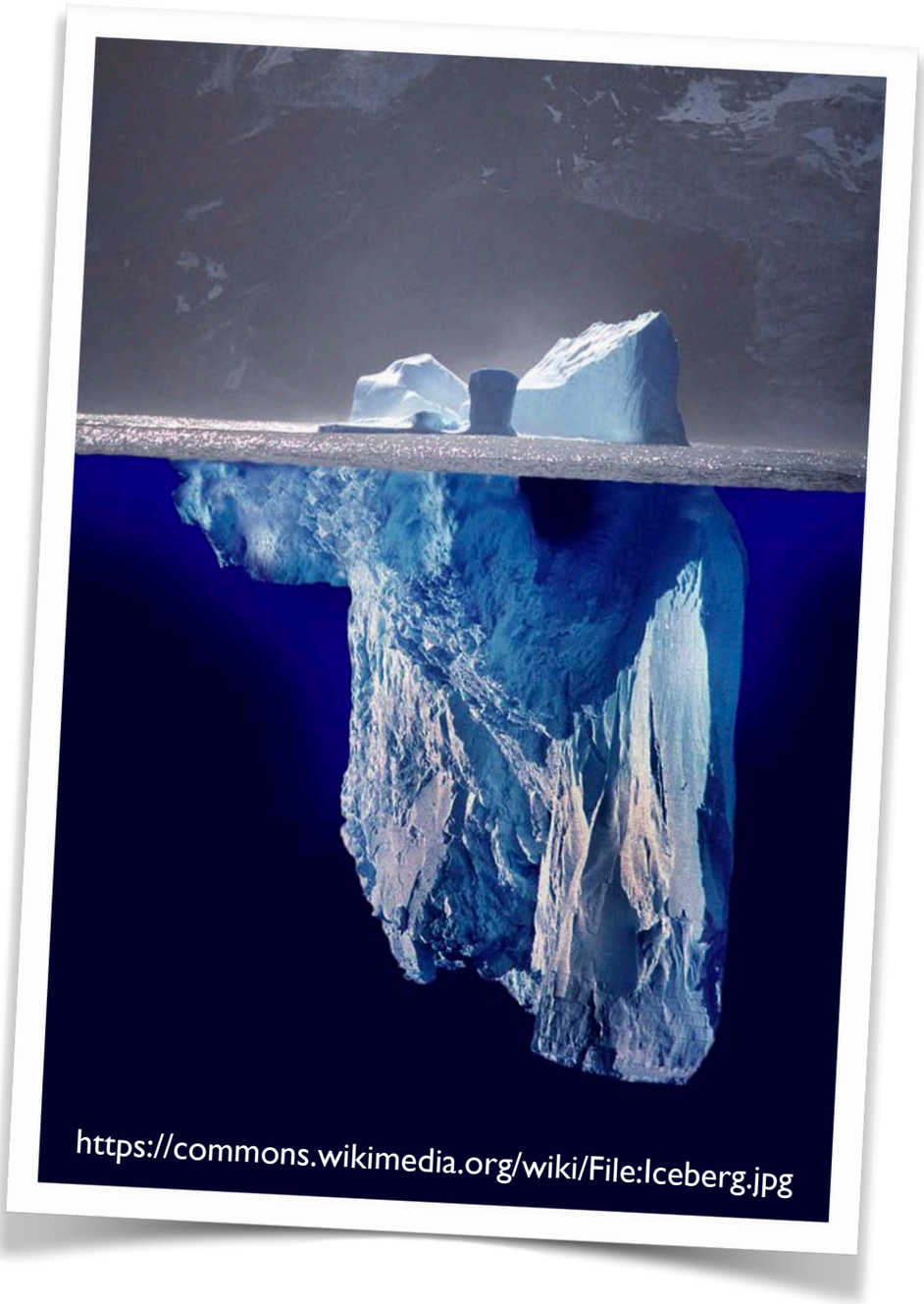
Totally submerged object



An object floating on the surface of a fluid



Example-5



What fraction of the volume of ice will be above/under the water when the ice is floating in water?

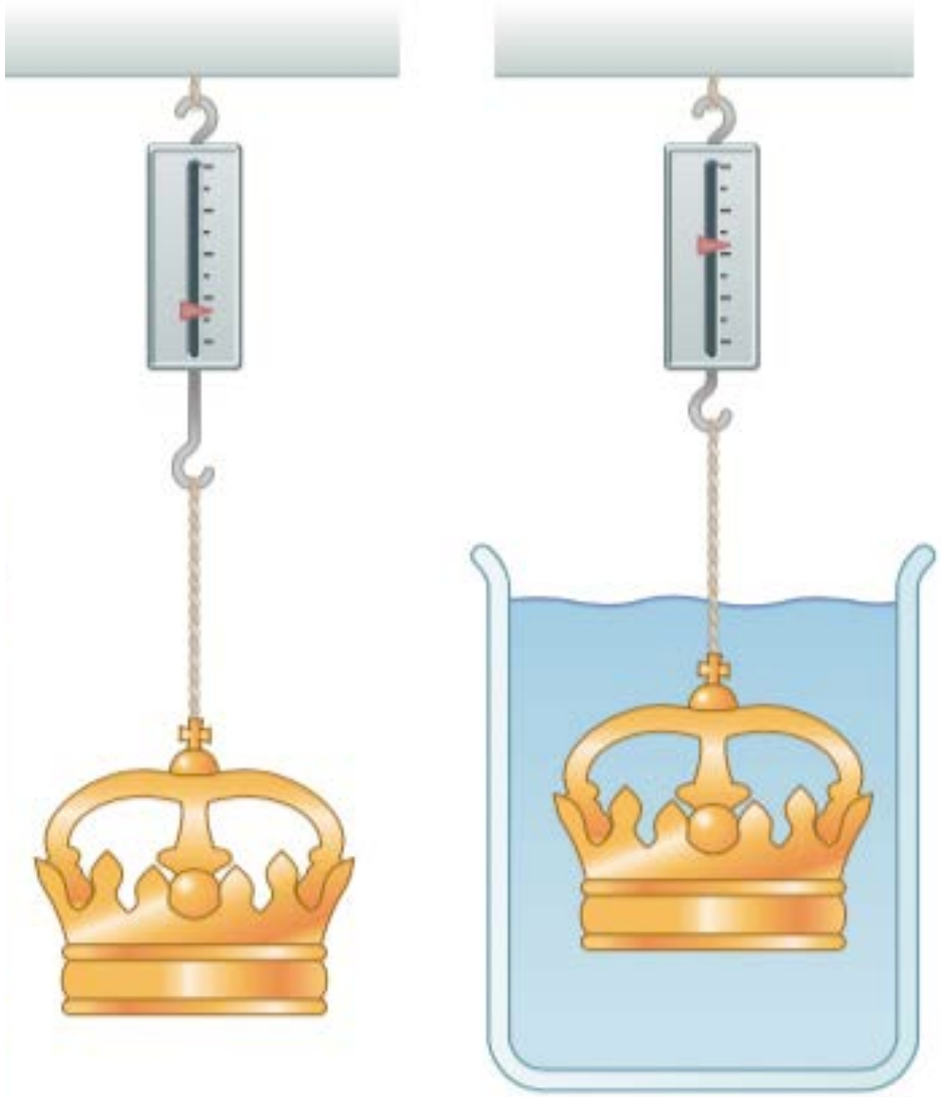
At 0 °C:

Density of ice = ~0.92 g/cm^3

Density of water = ~1.00 g/cm^3

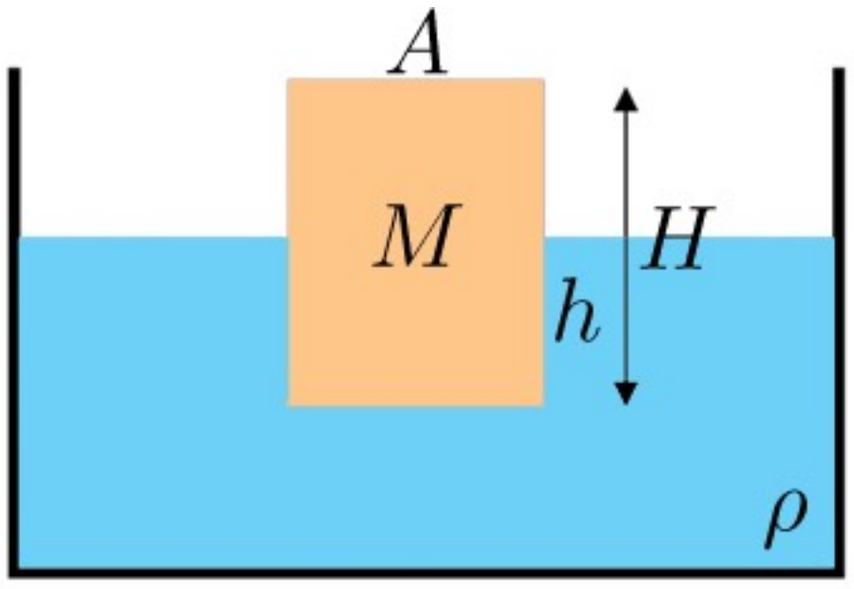
Example-6

Archimedes supposedly was asked to determine whether a crown made for the king consisted of pure gold. According to legend, he solved this problem by weighing the crown first in air and then in water as shown in Figure. Suppose the scale read 7.84 N when the crown was in air and 6.84 N when it was in water. What should Archimedes have told the king? [given $\rho_{water} = 10^3$ kg/m^3, $\rho_{gold} = 19.3 \times 10^3$ kg/m^3]



Example-6

Example-7



Consider an object that is floating and stationary in a liquid as shown in the figure. If we displace the object by a small amount from its equilibrium position, show that the motion of object can be described by SHM.

Example-7