Chapter #5

Fluids

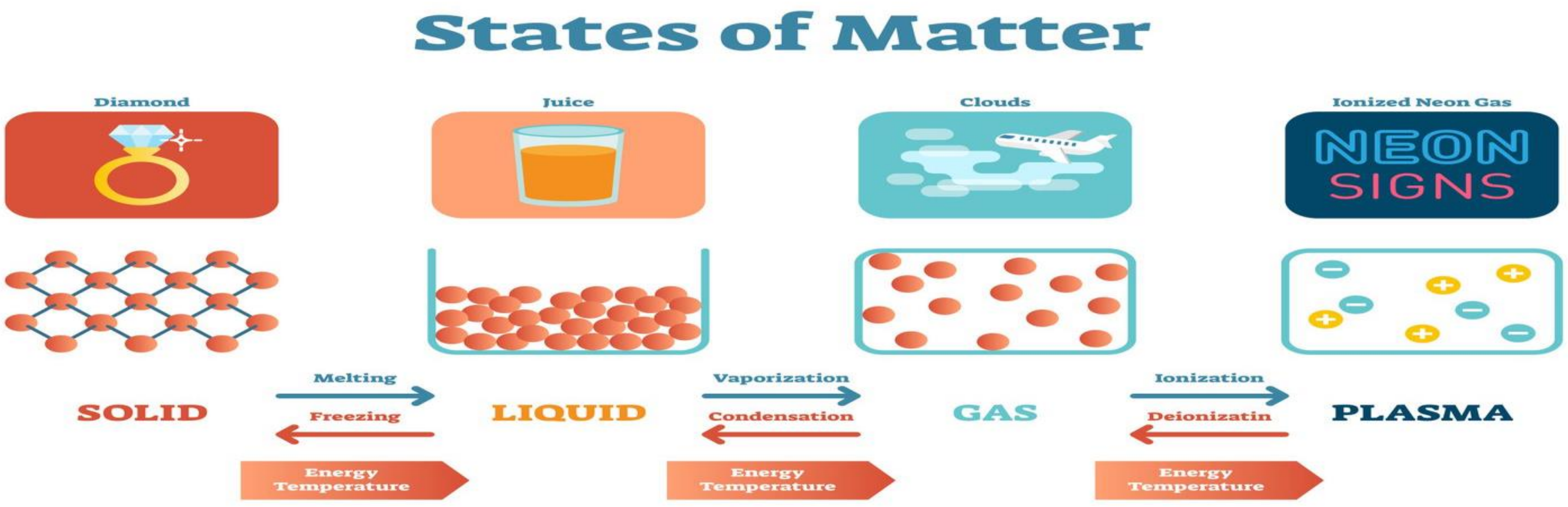
We will discuss:-

- State of matter.
- Pressure.
- Atmospheric Pressure.
- BAROMETER.
- Pascal’s Principle.
- Gravity and Pressure.
- Pressure and Depth.
- Archimedes’ Principle.
- The continuity equation.
- Viscosity.
- Viscous Drag .
- Surface tension.

States of matter

- Solid ⟶ Hold volume and shape.
- liquid ⟶ Hold volume , Adapt shape.
- Gas ⟶ Adapt Volume and shape.

Fluids (liquid, Gas)



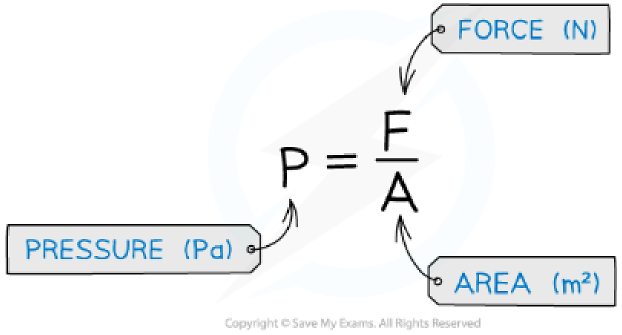
Pressure

- What is Pressure?
- The amount of force exerted on a surface per unit area is defined as **'Pressure'.** It can also be defined as the ratio of the force to the area.
- Formula and unit of pressure
- $P = \frac{F}{A}$
- The SI unit is pascals(Pa), where 1 Pa = $^{N}/_{m^2}$

Pressure

Pressure

- Pressure tells us how concentrated a force is, it is defined as the **force per unit area**

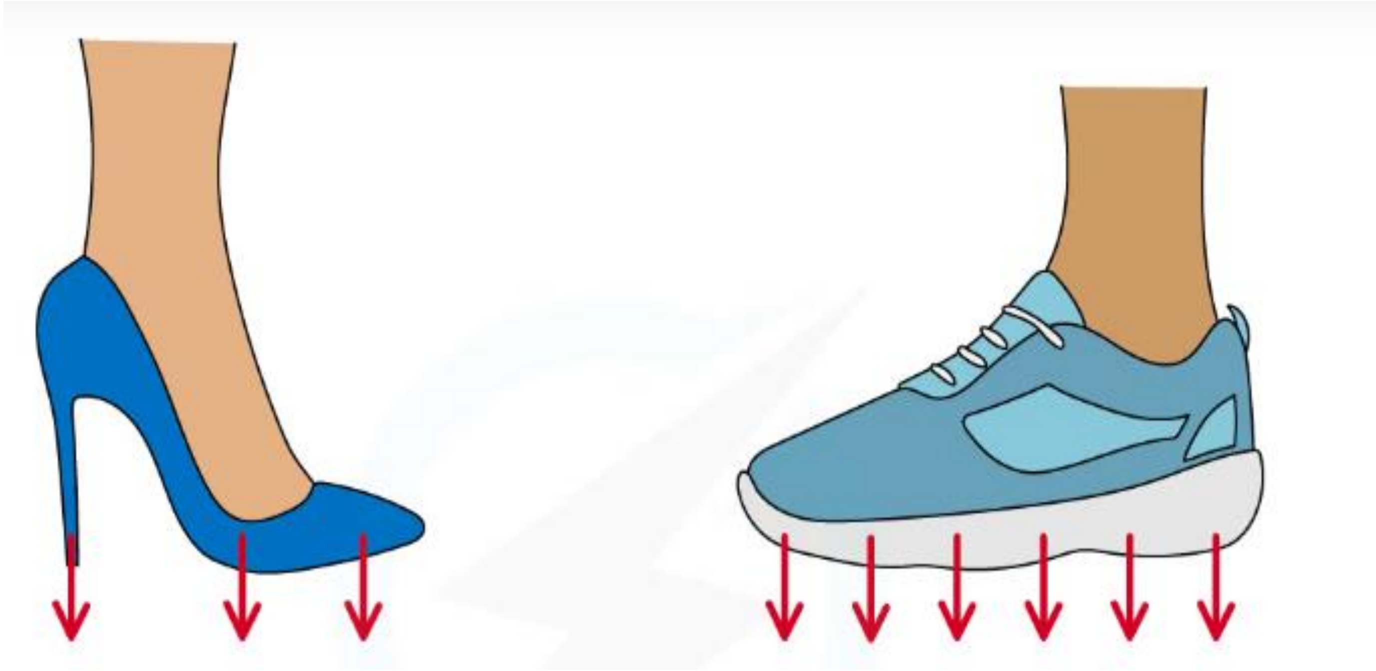


Pressure is equal to the force per unit area

- This equation tells us
  - If a force is spread over a large area it will result in a small pressure
  - If it is spread over a small area it will result in a large pressure

Discussion

- Which one has the lowest pressure , explain your answer .

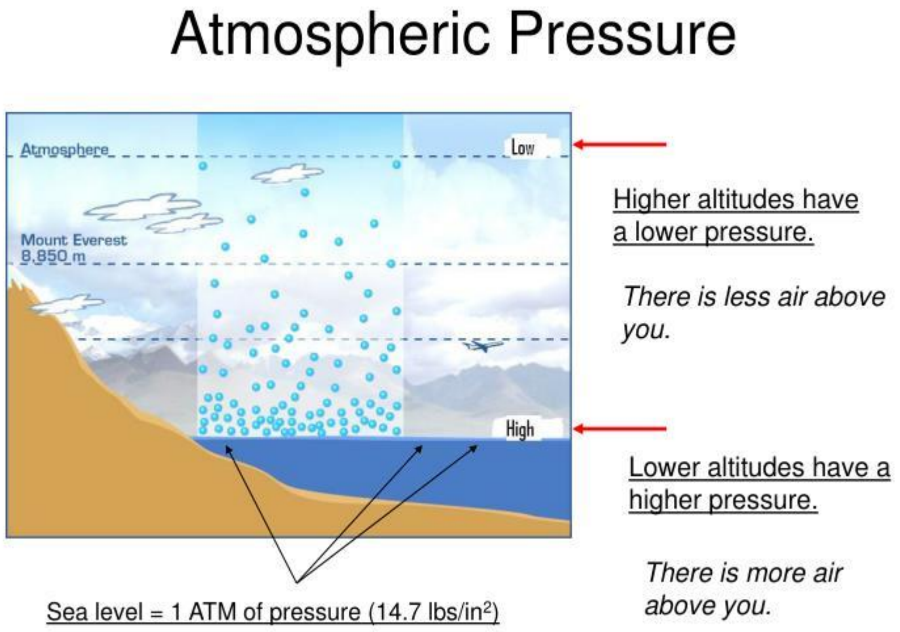


Example 1

- A force of 150 N is applied on an area of 1.5 m^2. Calculate the pressure exerted.

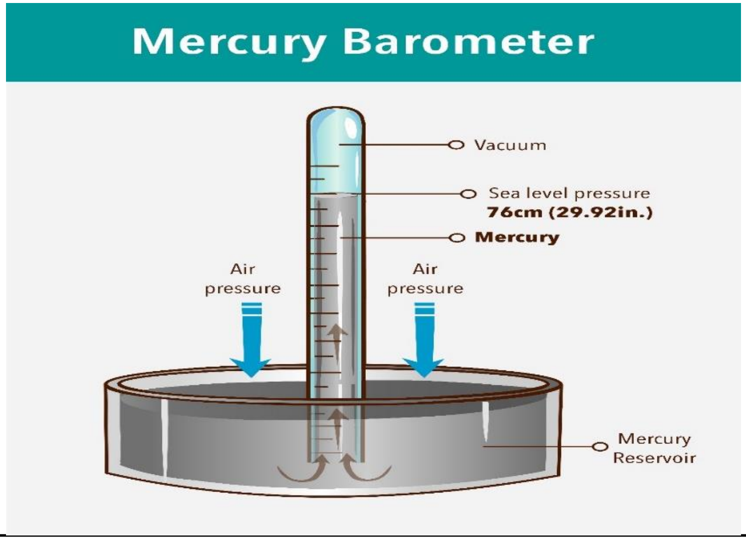
Atmospheric Pressure

- The earth's atmospheric air is surrounded by a layer of gases and so this air surrounding the earth exerts a pressure known as the **'atmospheric pressure'**. Its value at sea level is 101325 Pa.



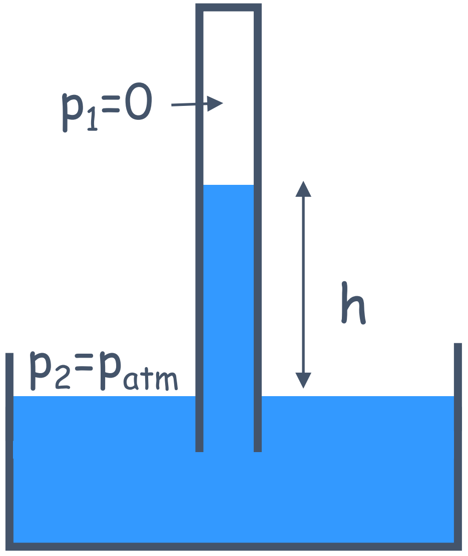
Barometer

- It is measured using a mercury barometer (hence atmospheric pressure is also known as barometric pressure), indicating the height of a column of mercury which exactly balances the weight of the column of atmosphere over the barometer.
- A barometer acts like a scale. In mercury barometer it measures the pressure of the atmosphere around you and pushes it against the liquid mercury . If the atmospheric pressure around you is high the mercury will rise



Barometer

- Barometer: a way to measure atmospheric pressure.
- $p_2 = p_1 + \rho gh$
- $p_{atm} = \rho gh$
- Measure h, determine p_{atm}
  - example--Mercury
  - $\rho = 13{,}600\ kg/m^3$
  - $p_{atm} = 1.05 \times 10^5$ Pa
  - $\Rightarrow h = 0.757$ m = 757 mm (for 1 atm)



Pascal's Principle

Pascal's Principle

A *change in pressure* at any point in a confined fluid is transmitted everywhere throughout the fluid.

- **Applications of Pascal's Principle**

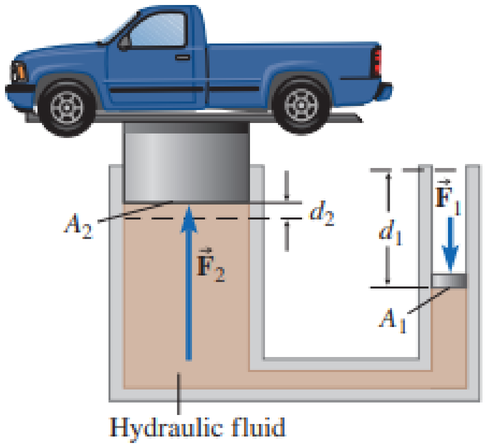
Applications of Pascal's Principle

- Hydraulic Lift

  $\Delta P_1 = \Delta P_2$

  $F_1/A_1 = F_2 / A_2$

  $F_1 = F_2 (A_1/A_2)$

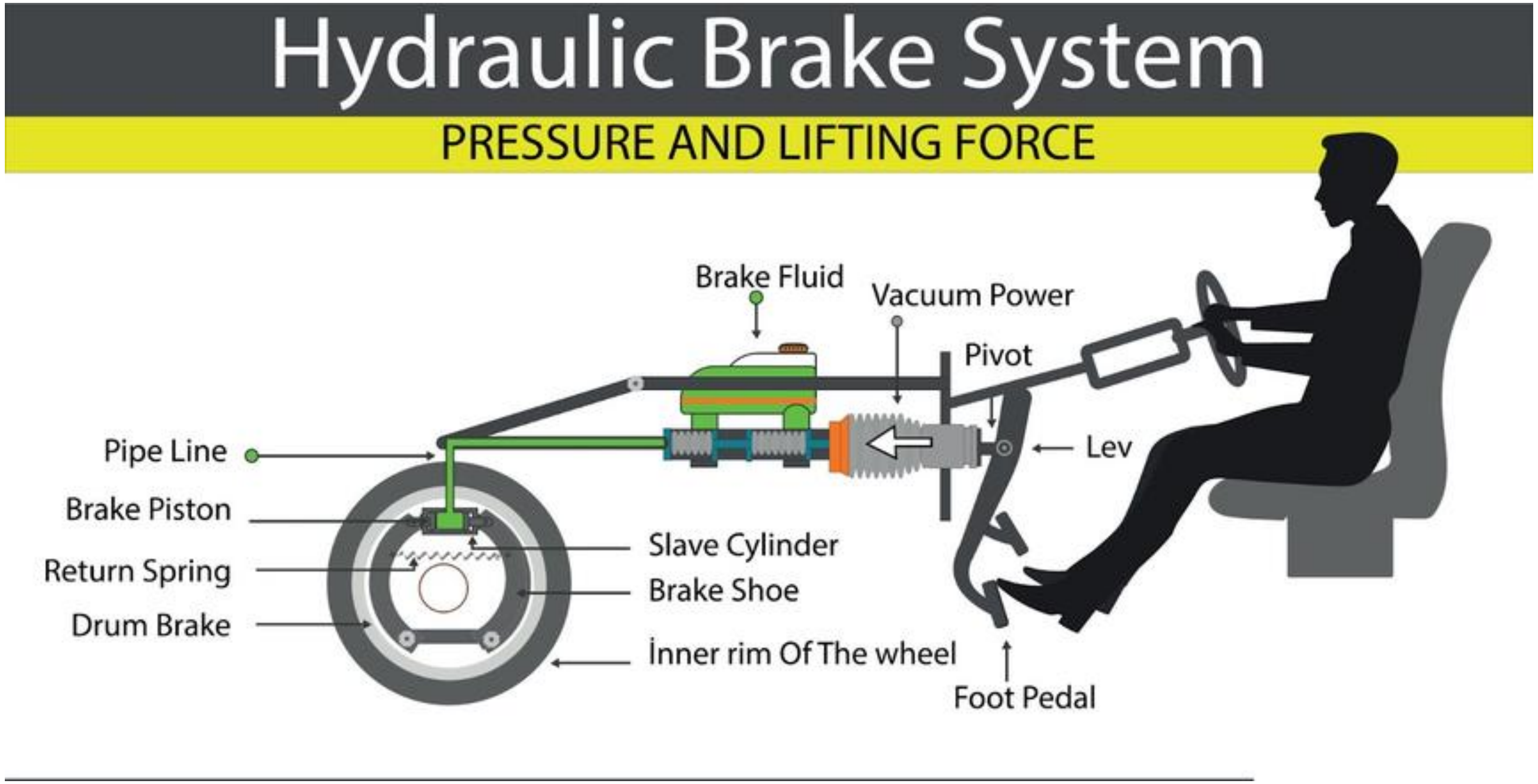


  - Compare the work done by F_1 with the work done by F_2

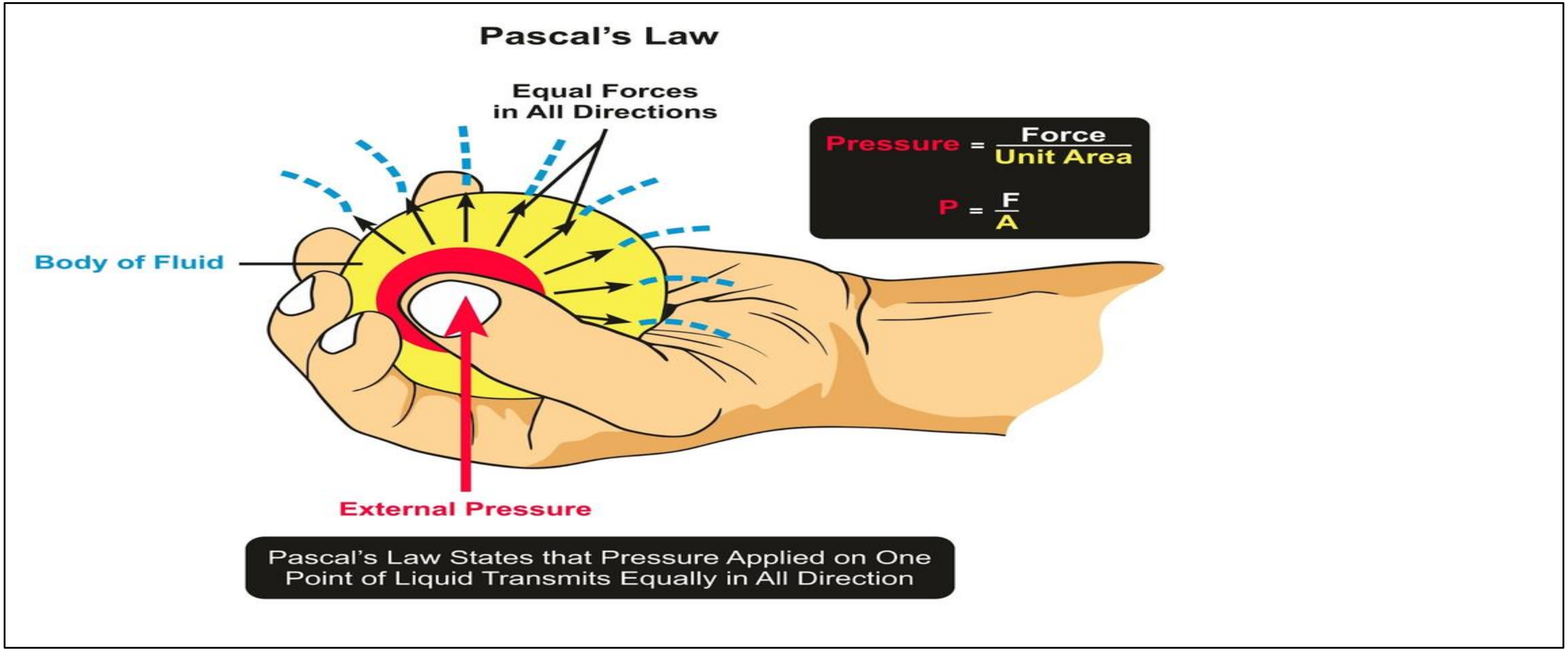
A) $W_1 > W_2$ B) $W_1 = W_2$ C) $W_1 < W_2$

Applications of Pascal’s Principle

- Hydraulic Brakes



Pascal’s Principle



Pascal's Principle

What happens when you squeeze a tube of toothpaste?

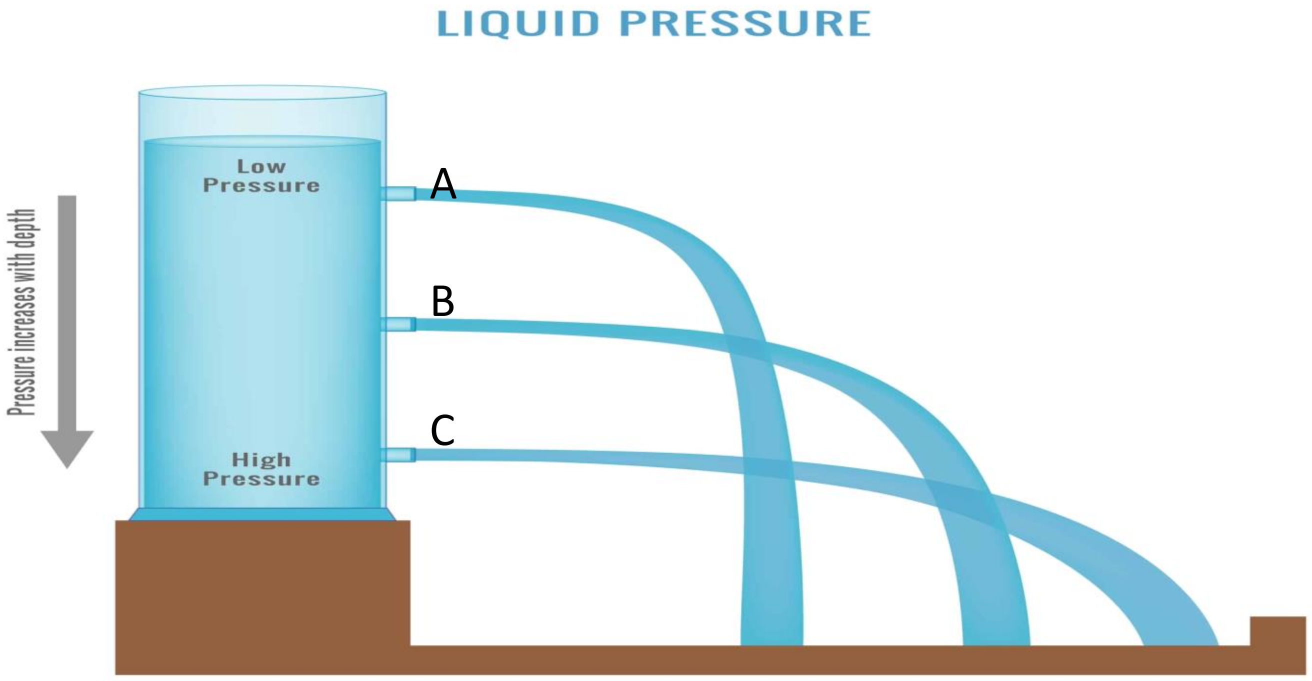
$P_1 = P_2$

Pascal's Principle: A Change in pressure at any point in an enclosed fluid will be transmitted equally to all parts of the fluid.

$$F_1 / A_1 = F_2 / A_2$$

Pressure in liquid

- Which holes has the greatest pressure , Explain your answer ?



Pressure in liquid

- **Pressure variation with depth in a static fluid with uniform density**

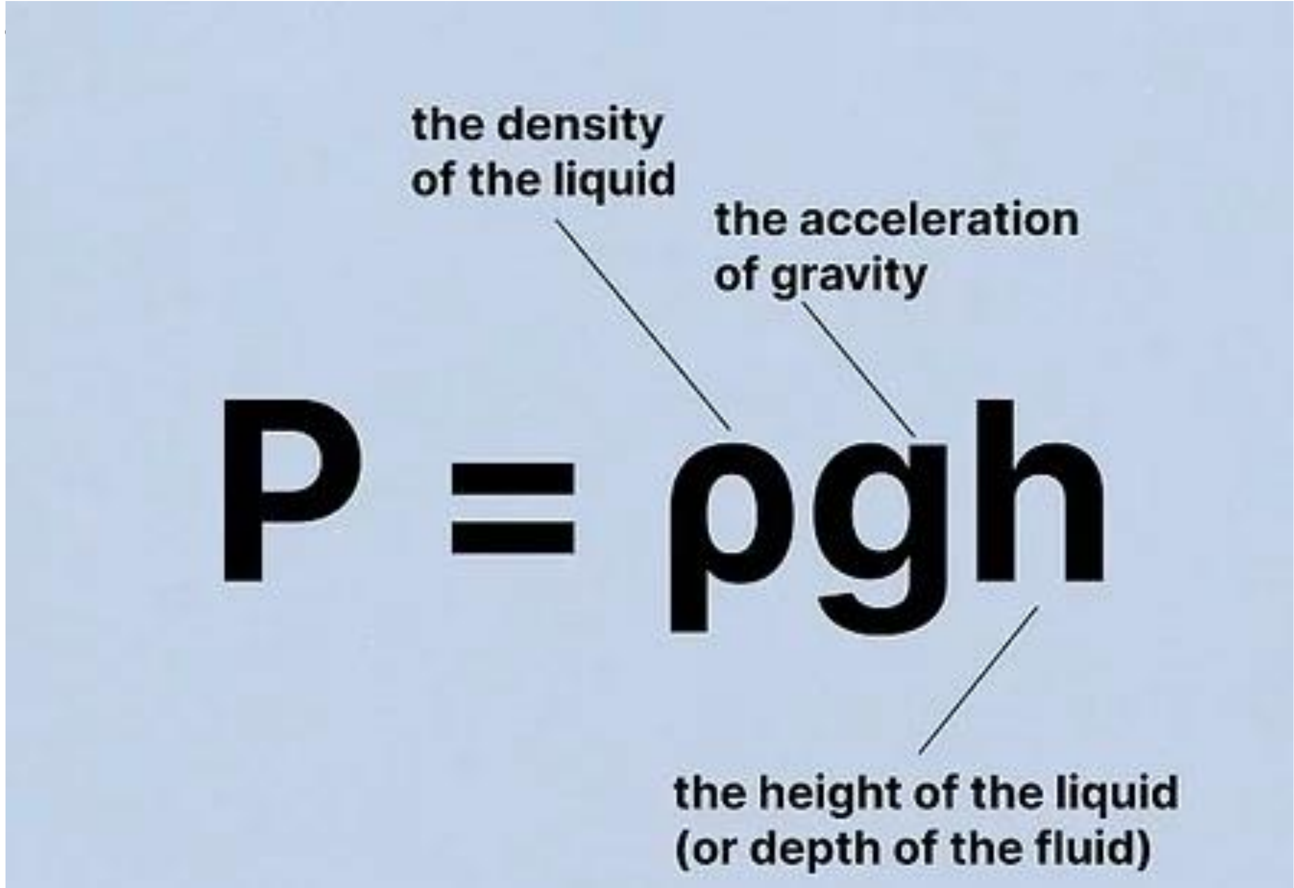
  $$P_2 = P_1 + \rho g d \quad \text{(9-12)}$$

  where point 2 is a depth d below point 1

  Pressure at a depth d below the surface of a liquid open to the atmosphere

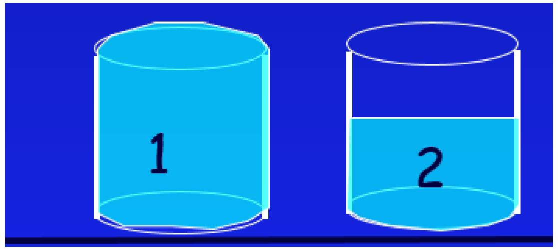
  $$P = P_{atm} + \rho g d \quad \text{(9-13)}$$

Gravity and Pressure.



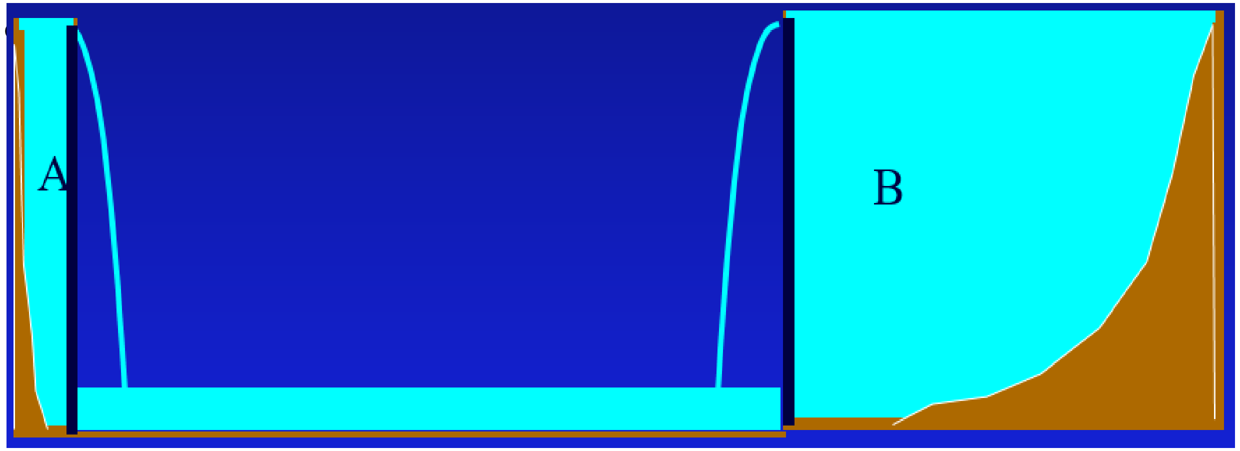
Gravity and Pressure.

- Two identical "light" containers are filled with water. The first is completely full of water, the second container is filled only ½ way. Compare the pressure each container exerts on the table.
- A) $P_1 > P_2$ B) $P_1 = P_2$ C) $P_1 < P_2$



- $P = F/A$
- $= mg / A$
- Cup 1 has greater mass, but same area

Dam Act



Two dams of equal height prevent water from entering the basin. Compare the net force due to the water on the two dams.

A) $F_A > F_B$ B) $F_A = F_B$ C) $F_A < F_B$

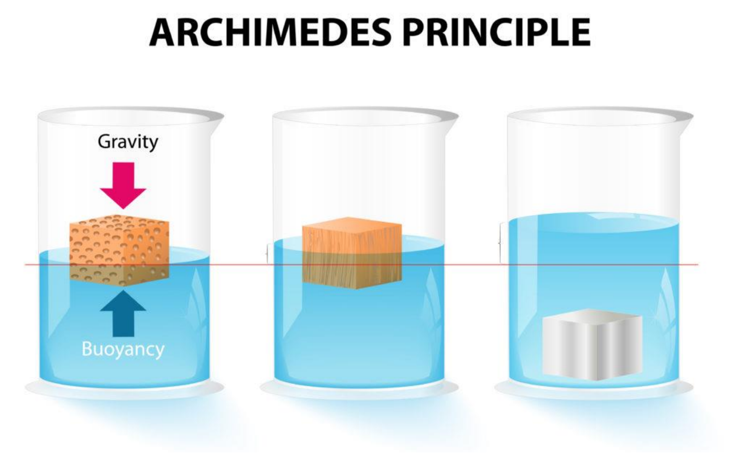
F = P A, and pressure is ρgh. Same pressure, same Area same force even though more water in B!

Example

- A diver swims to a depth of 3.2 m in a freshwater lake. Find the force pushing in on her eardrum (The A of eardrum =6x10^{-5} m^2

ρ_w=1000Kg/m^3

Archimedes' Principle

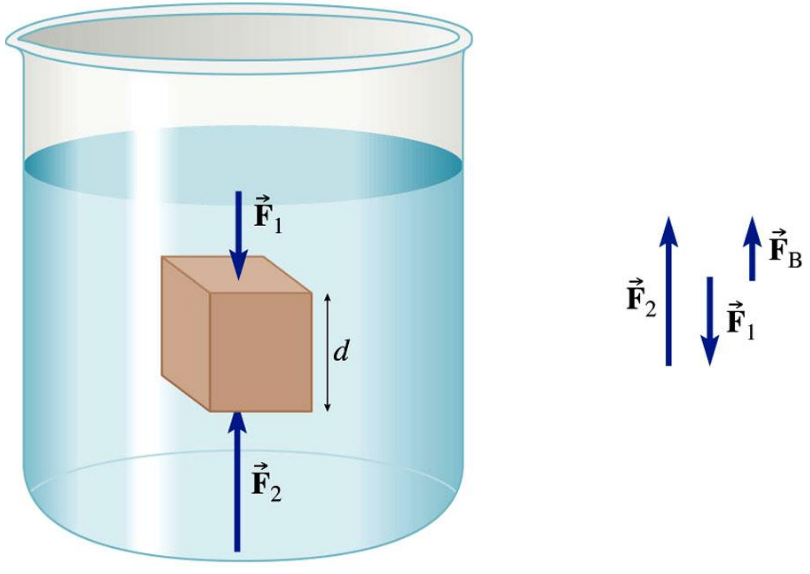


Archimedes' Principle

A fluid exerts an upward buoyant force on a submerged object equal in magnitude to the weight of the volume of fluid displaced by the object.

Archimedes' Principle

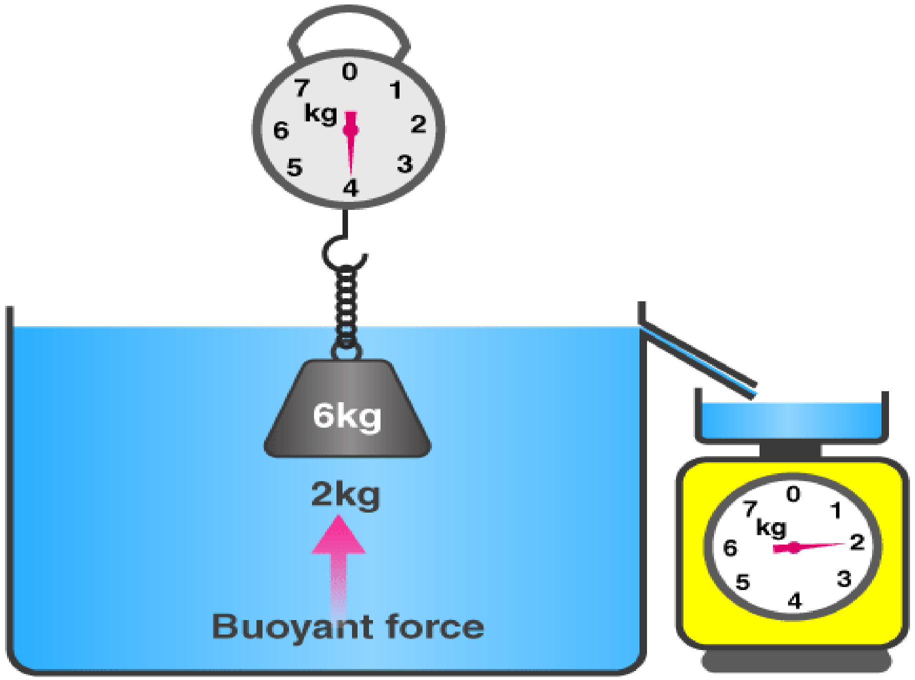
- Determine force of fluid on immersed cube
  - Draw FBD
    - $F_B = F_2 - F_1$
    - $= P_2 A - P_1 A$
    - $= (P_2 - P_1)A$
    - $= \rho g d A$
    - $= \rho g V$



(a) (b)

- Buoyant force is weight of displaced fluid!

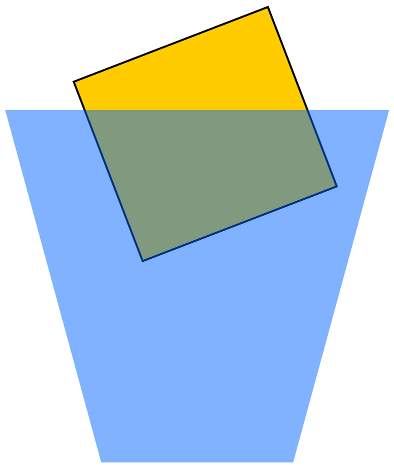
Archimedes’ Principle

- Buoyant force is weight of displaced fluid!
- 

What do you think?

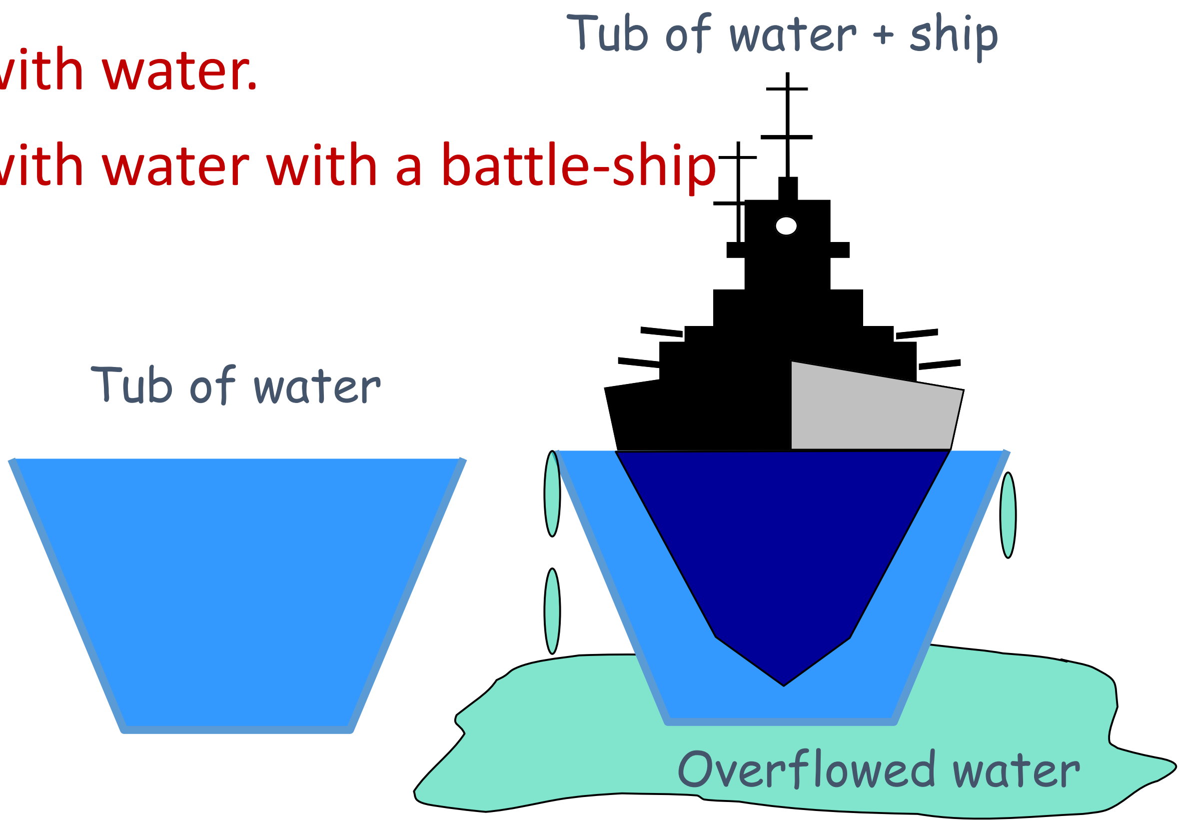
- Suppose you float a large ice-cube in a glass of water, and that after you place the ice in the glass the level of the water is at the very brim. When the ice melts, the level of the water in the glass will:

1. Go up, causing the water to spill out of the glass.
2. Go down.
3. Stay the same.



What do you think?

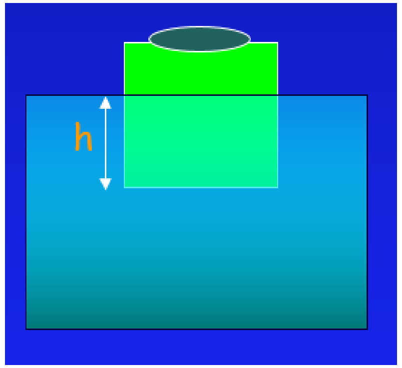
- Which weighs more:
  1. A large bathtub filled to the brim with water.
  2. A large bathtub filled to the brim with water with a battle-ship floating in it.
  3. They will weigh the same.



Weight of ship = Buoyant force = Weight of displaced water

Archimedes Example

- A cube of plastic 4.0 cm on a side with density = 0.8 g/cm^3 is floating in the water. When a 9 gram coin is placed on the block, how much does it sink below water surface?



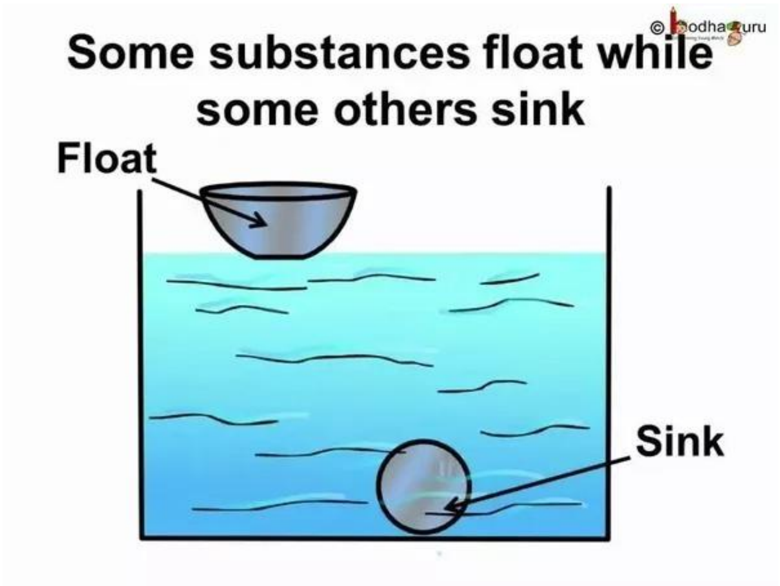
Summary

- Pressure is force exerted by molecules "bouncing" off container $P = F/A$
- Gravity/weight effects pressure
  - $P = P_0 + \rho g d$
- Buoyant force is "weight" of displaced fluid. $F = \rho\ g\ V$

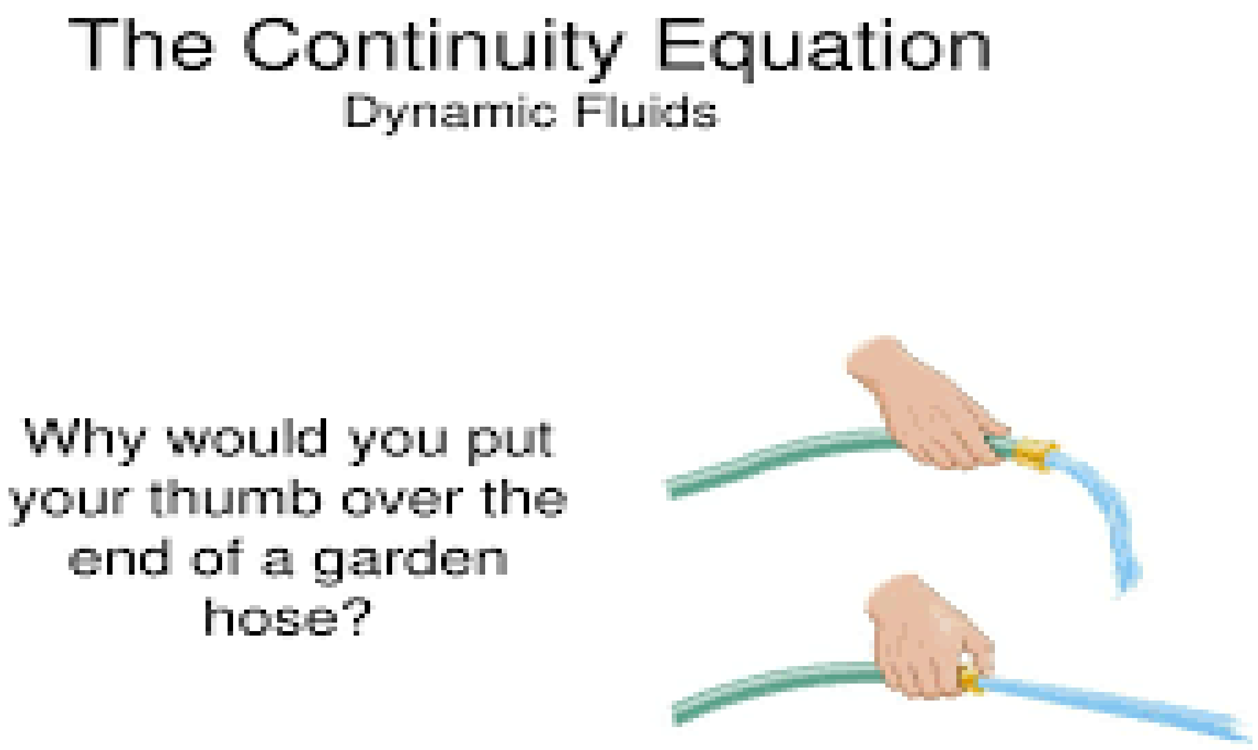
Archimedes' Principle

- Buoyant Force (F_B)
  - weight of fluid displaced
  - $F_B = \rho_{fluid} V_{displaced}\, g$
  - $F_g = mg = \rho_{object}\, V_{object}\, g$
  - object sinks if $\rho_{object} > \rho_{fluid}$
  - object floats if $\rho_{object} < \rho_{fluid}$

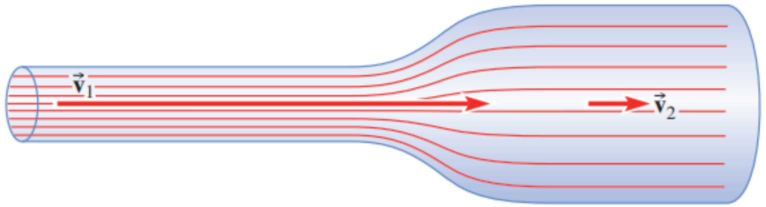
- If object floats…
  - $F_B = F_g$
  - Therefore: $\rho_{fluid}\, g\, V_{displ.} = \rho_{object}\, g\, V_{object}$
  - Therefore: $V_{displ.}/V_{object} = \rho_{object} / \rho_{fluid}$



Continuity of Fluid Flow



Continuity of Fluid Flow

- 

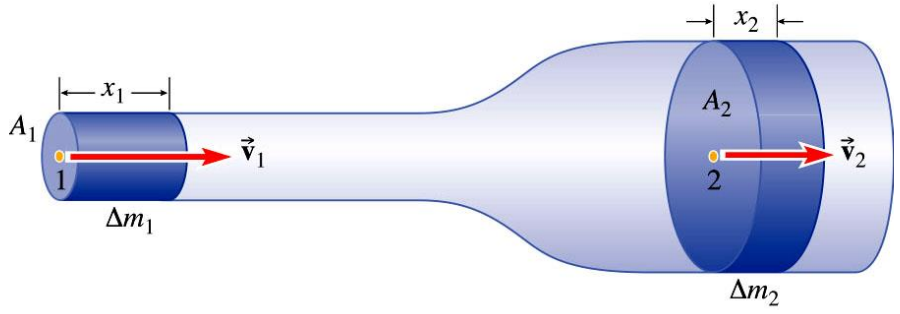
Continuity equation for incompressible fluid

$$A_1 v_1 = A_2 v_2 \quad (9\text{-}35)$$

Continuity of Fluid Flow

- Watch "plug" of fluid moving through the narrow part of the tube (A_1)
  - •Time for "plug" to pass point $\Delta t = x_1 / v_1$
  - • Mass of fluid in "plug" $m_1 = \rho V_1 = \rho A_1 x_1$ or $m_1 = \rho A_1 v_1 \Delta t$
- Watch "plug" of fluid moving through the wide part of the tube (A_2)
  - •Time for "plug" to pass point $\Delta t = x_2 / v_2$
  - • Mass of fluid in "plug" $m_2 = \rho V_2 = \rho A_2 x_2$ or $m_2 = \rho A_2 v_2 \Delta t$
- Continuity Equation says $m_1 = m_2$ fluid isn't building up or disappearing

$$A_1 v_1 = A_2 v_2$$

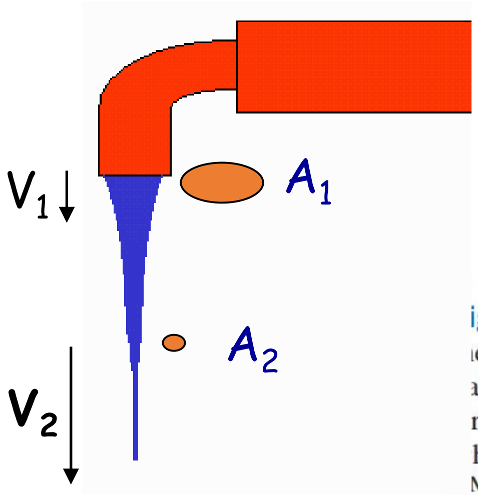


Continuity of Fluid Flow

A stream of water gets narrower as it falls from a faucet (try it & see).

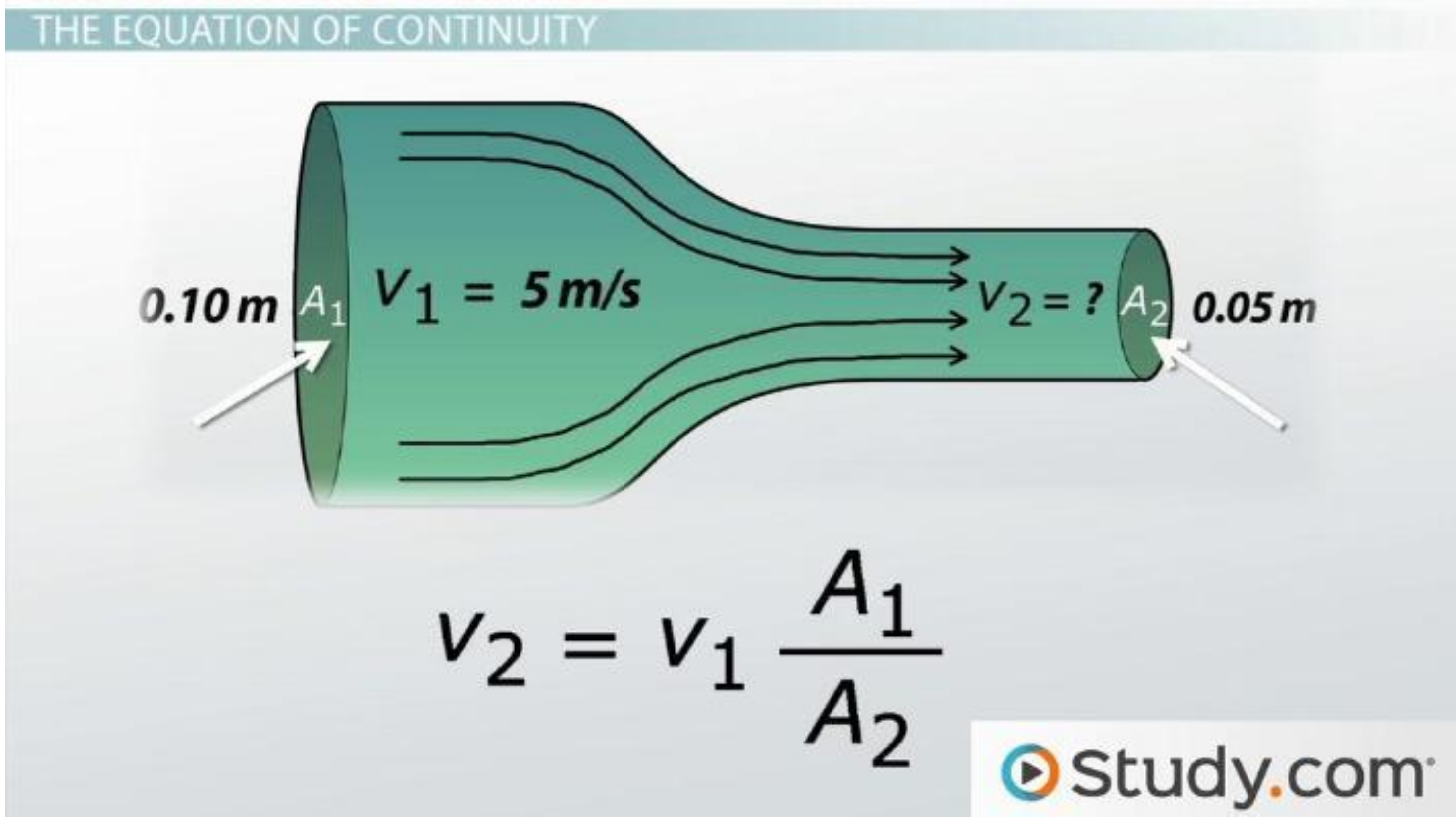
Explain this phenomenon using the equation of continuity.

$A_1v_1=A_2v_2$. as it falls down, A will be decreased. on the other hand V will be increased b/c of gravity. therefore, this phenomenon is appropriate for the equation of continuity

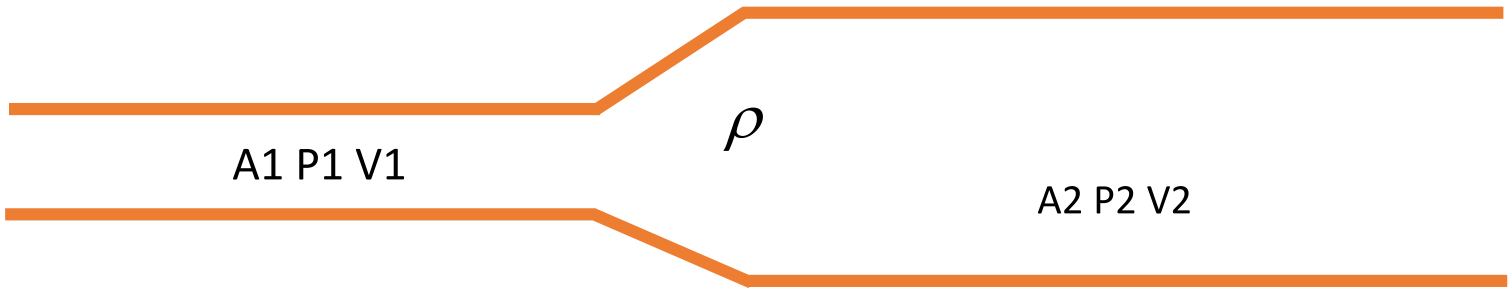


igure 9.23 Demonstrating
ıe continuity equation at a
athroom sink. Notice that the
ream of water is narrower
here the flow speed is faster.
Michael Bodmann/Getty Images

Continuity of Fluid Flow



Fluid Flow Concepts

- 

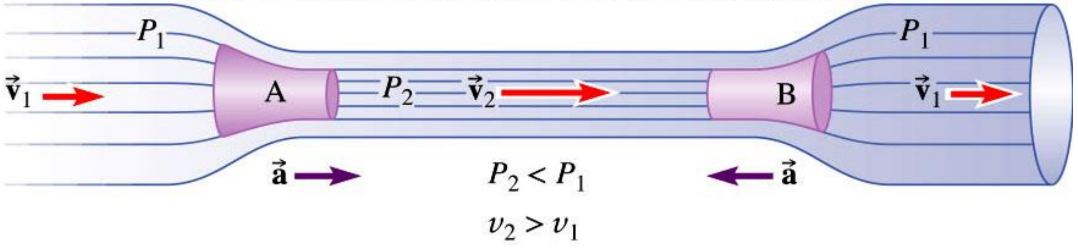
  - **Mass flow rate** = **ρAv (kg/s)**
  - **Volume flow rate** = **Av (m^3/s)**
  - Continuity: $A_1 v_1 = A_2 v_2$

    i.e., mass flow rate the same everywhere

    e.g., flow of river

Pressure, Flow and Work

- Continuity Equation says fluid speeds up going to smaller opening, slows down going to larger opening
- Acceleration due to change in pressure. $P_1 > P_2$
  - Smaller tube has faster water and LOWER pressure
- Change in pressure does work!
  - $W = P_1A_1\Delta x_1 - P_2A_2\Delta x_2 = (P_1 - P_2)V$

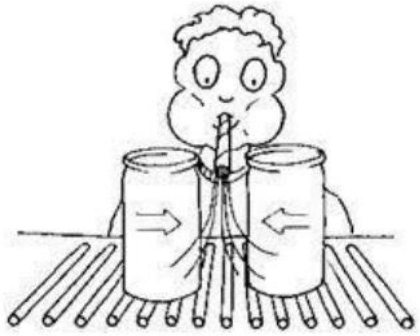


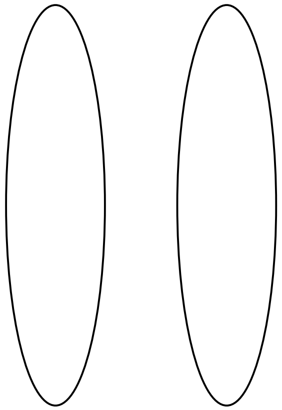
(a)

Pressure ACT

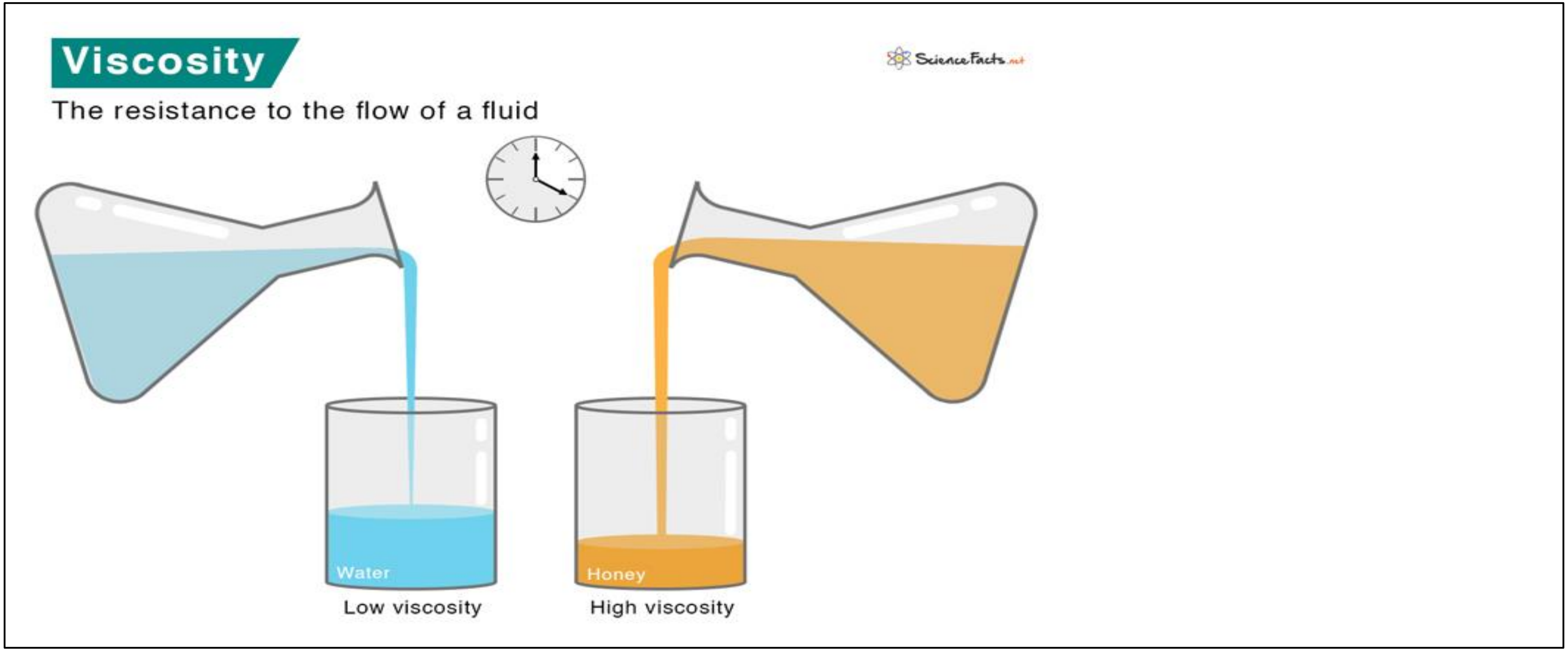
- What will happen when I “blow” air between the two plates?

A) Move Apart B) Come Together C) Nothing





Viscosity



Viscosity
The resistance to the flow of a fluid
ScienceFacts
Water
Honey
Low viscosity
High viscosity

Viscosity

- A real fluid has viscosity (fluid friction). This implies a pressure difference needs to be maintained across the ends of a pipe for fluid to flow.
- Viscosity also causes the existence of a velocity gradient across a pipe. A fluid flows more rapidly in the center of the pipe and more slowly closer to the walls of the pipe.
- The volume flow rate for laminar flow of a viscous fluid is given by Poiseuille's Law.

$$\frac{\Delta V}{\Delta t} = \frac{\pi}{8} \frac{\Delta P / L}{\eta} r^4$$

where η is the viscosity

Viscosity

- Example (text problem): A hypodermic syringe attached to a needle has an internal radius of 0.300 mm and a length of 3.00 cm. The needle is filled with a solution of viscosity 2.00×10^{-3} Pa sec; it is injected into a vein at a gauge pressure of 16.0 mm Hg.

  (a) What must the pressure of the fluid in the syringe be in order to inject the solution at a rate of 0.150 mL/sec?

Example continued:

- This pressure difference is between the fluid in the syringe and the fluid in the vein; it is the given gauge pressure.

$$\Delta P = P_s - P_v$$

$$P_s = P_v + \Delta P$$

$$= 2130 \text{ Pa} + 2830 \text{ Pa} = 4960 \text{ Pa}$$

- (b) What force must be applied to the plunger, which has an area of 1.00 cm^2?

Viscous Drag

- When an object moves through a fluid, the fluid exerts a drag force on it. When the relative velocity between the object and the fluid is low enough for the flow around the object to be laminar, the drag force derives from viscosity and is called viscous drag. The viscous drag force is proportional to the speed of the object

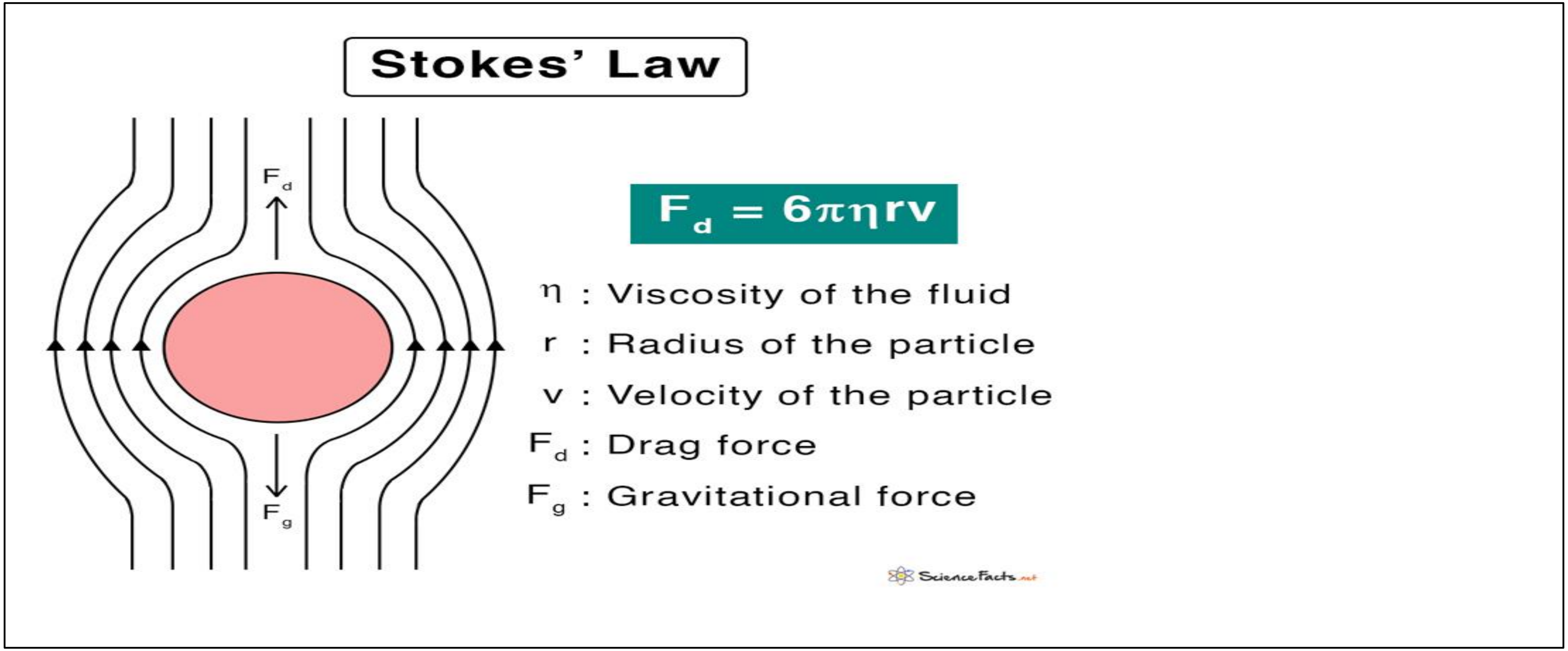
($F_D \propto$ v). For larger relative speeds, the flow becomes turbulent and the drag force is proportional to the square of the object's speed ($F_D \propto V^2$). The viscous drag force depends also on the shape and size of the object. For a spherical object, the viscous drag force is given by Stokes's law:

Stokes's law (viscous drag on a sphere)

$$F_D = 6\pi\eta r v \qquad (9\text{-}43)$$

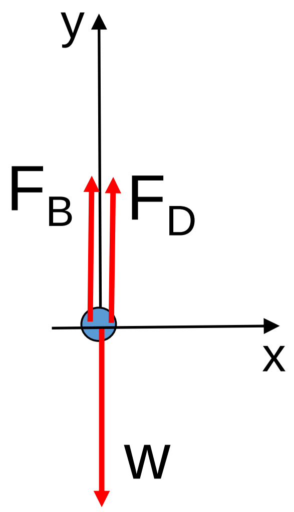
where r is the radius of the sphere, η is the viscosity of the fluid, and v is the speed of the object with respect to the fluid.

Viscous Drag



Example

- Example (text problem 9.72): A sphere of radius 1.0 cm is dropped into a glass cylinder filled with a viscous liquid. The mass of the sphere is 12.0 g and the density of the liquid is 1200 kg/m^3. The sphere reaches a terminal speed of 0.15 m/s. What is the viscosity of the liquid?



Apply Newton's Second Law to the sphere

Surface tension

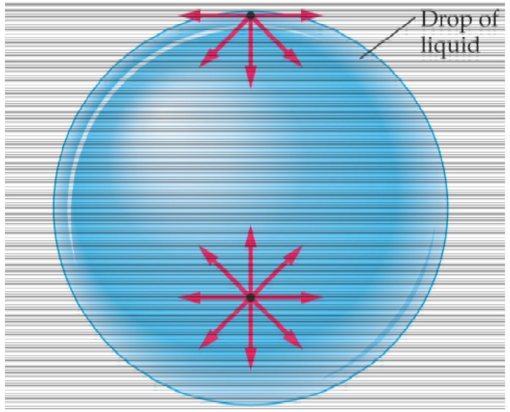
- The surface of a liquid has special properties not associated with the interior of the liquid. The surface acts like a stretched membrane under tension. The surface tension (symbol γ, the Greek letter gamma) of a liquid is the force per unit length with which the surface pulls on its edge. The direction of the force is tangent to the surface at its edge. Surface tension is caused by the cohesive forces that pull the molecules toward each other.

Figure 9.31 *Gerris lacustris*, commonly known as a water strider. Notice the indentations in the water surface. The water surface is stretched at these indentations and, as a result, exerts an upward force on the strider's legs.

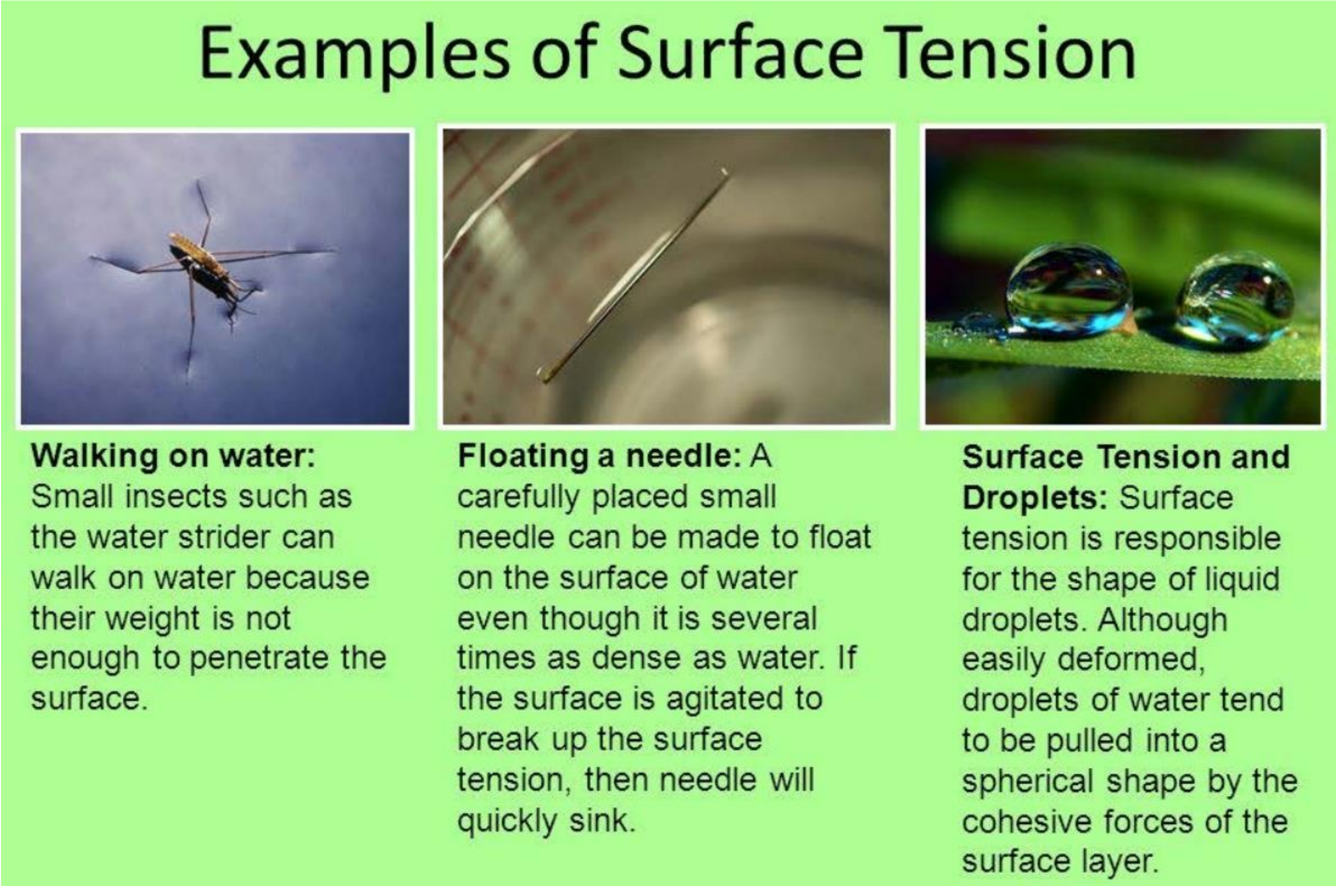
Surface tension

- The net effect of surface tension is to make the surface area of a liquid as small as possible (the least surface area), i.e. a sphere
- The origin of surface tension:

A molecule in the interior of a fluid experiences attractive forces of equal magnitude in all directions, giving a net force of zero. A molecule near the surface of the fluid experiences a net attractive force toward the interior of the fluid. This causes the surface to be pulled inward, resulting in a surface of minimum area.



Surface tension



Surface tension

- Medical application :

Surface tension prevents alveoli rupture during inhalation.

During exhalation surface tension shrinks alveoli. The alveoli secrete a surfactant that decreases surface tension so that alveoli stop shrinking.

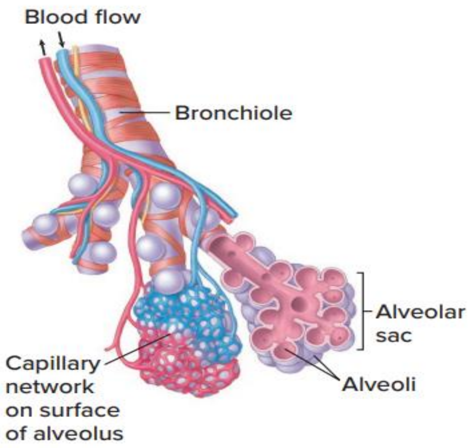


Figure 9.32 In the human lung, millions of tiny sacs called alveoli are inflated with each breath. Gas is exchanged between the air and the blood through the walls of the alveoli. The total surface area through which gas exchange takes place is about 80 m^2—about 40 times the surface area of the body.

Surface tension

- Example (text problem 9.78): Assume a water strider has a roughly circular foot of radius 0.02 mm. (a) What is the maximum possible upward force on the foot due to surface tension of the water? (b) What is the maximum mass of this water strider so that it can keep from breaking through the water surface? The strider has six legs.