Fluid Mechanics

PHYS102~L 7

Topics to be covered:

- ❖ Density
- ❖ Pressure
- ❖ Variation of Pressure with Depth
- ❖ Pressure Measurements
- ❖ Buoyant Forces-Archimedes Principle
- ❖ Equation of Continuity for Fluids
- ❖ Bernoulli's Equation
- ❖ Boyle’s law
- ❖ Surface Tension
- ❖ Viscosity

Content's Reference

****PLEASE NOTE, THE CONTENT IN THIS PRESENTATION IS JUST TO HELP YOU, AND IT IS NOT A SUBSTITUTE TO THE COURSE REFERENCES**

You can find the lecture topics in:

- **Course Reference: Physics for scientists and Engineers, Raymond Serway & et al 9th edition**

Chapter (14)

- Pressure(14.1) [p417 to p419]
- Variation of Pressure with Depth (14.2) [p419 to p421]
- Pressure Measurements (14.3) [p423]
- Buoyant Forces-Archimedes Principle(14.4) [p423 to p426]
- Fluid dynamics (14.5) [p427+p428]
- Equation of Continuity for Fluids(14.5) [p419 to p421]
- Bernoulli's Equation (14.6) [p30 to p433]

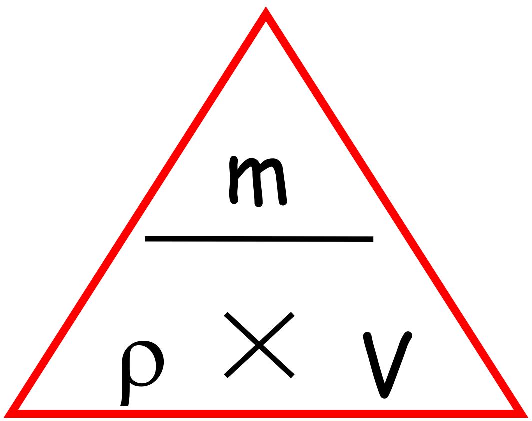
Density

g or kg

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

g .cm^{-3} or kg .m^{-3}

cm^3 or m^3

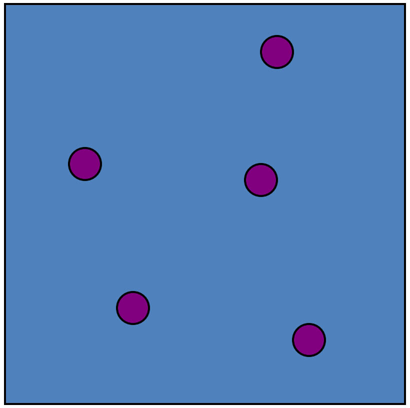


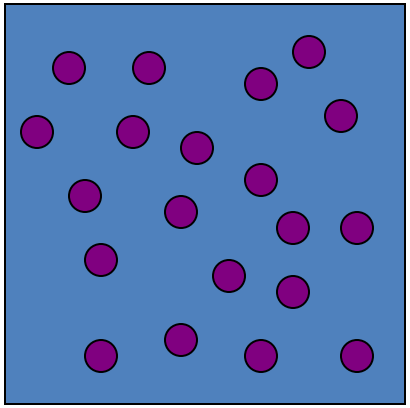
$$\rho = m \backslash V$$

- Density is defined as: amount of matter per unit volume
- In other word: is the **<u>ratio</u>** of mass to volume.

Which one is more dense?

- How about this: Which square is more dense?





Liquid Layers

- Which layer has the highest density?
- Which layer has the lowest density?

- Imagine that the liquids have the following densities:
  - $10\ g/cm^3$. $3\ g/cm^3$.
  - $6\ g/cm^3$. $5\ g/cm^3$.

Which number would go with which layer?

What is the mean of FLUID

- Matter is normally classified as being in one of four states: solid, liquid, gas, and plasma.

- All of liquids, gases, and plasma are 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.

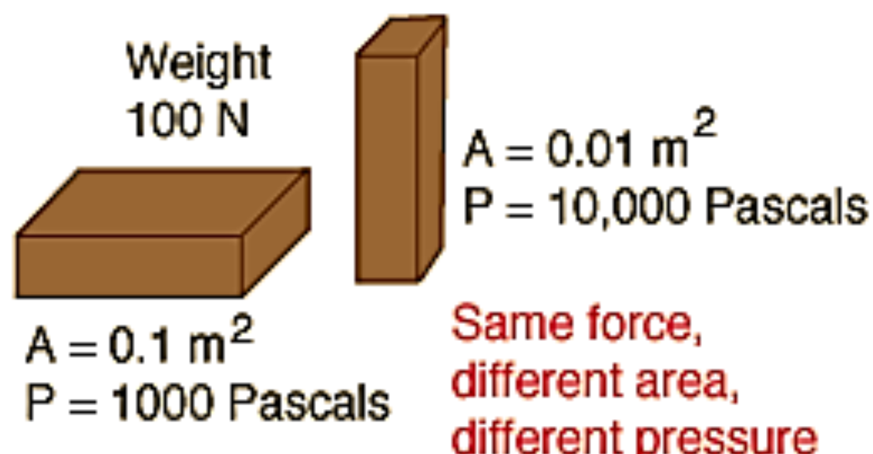
Fluid Mechanics

- ✓ Fluid mechanics is the study of how fluids move and the forces on them.
- ✓ Fluid mechanics can be divided into:
  - fluid statics, the study of fluids at rest.
  - fluid dynamics, the study of fluids in motion..

Pressure

- ✓ Pressure is defined as force per unit area.
- ✓ The standard unit for pressure is the Pascal, which is a Newton per square meter.
- ✓ Pressure is a scalar quantity.

$$Pressure = \frac{Force}{Area} = \frac{F}{A}$$

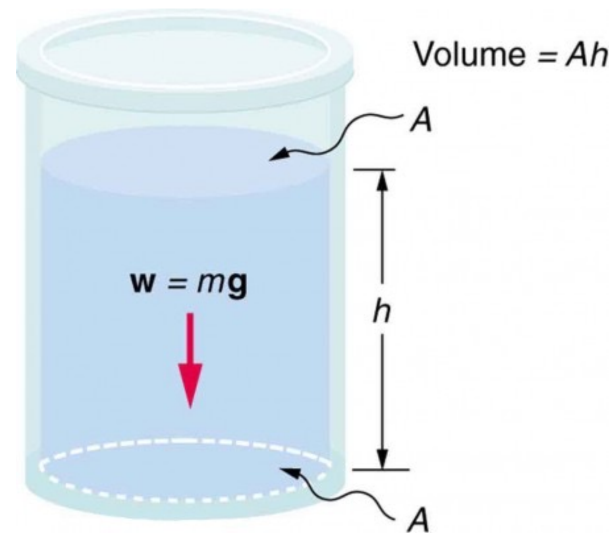


Variation of Pressure with Depth

- **One might guess that the deeper you go into a liquid or gas, the pressure on you from the surrounding fluid will be greater . The reason for the increased pressure is that the deeper into a fluid you go, the more fluid, and thus the more weight, you have over top of you.**

- **We can calculate the variation of pressure with depth by considering a volume of fluid of height *h* and cross-sectional area *A*.**

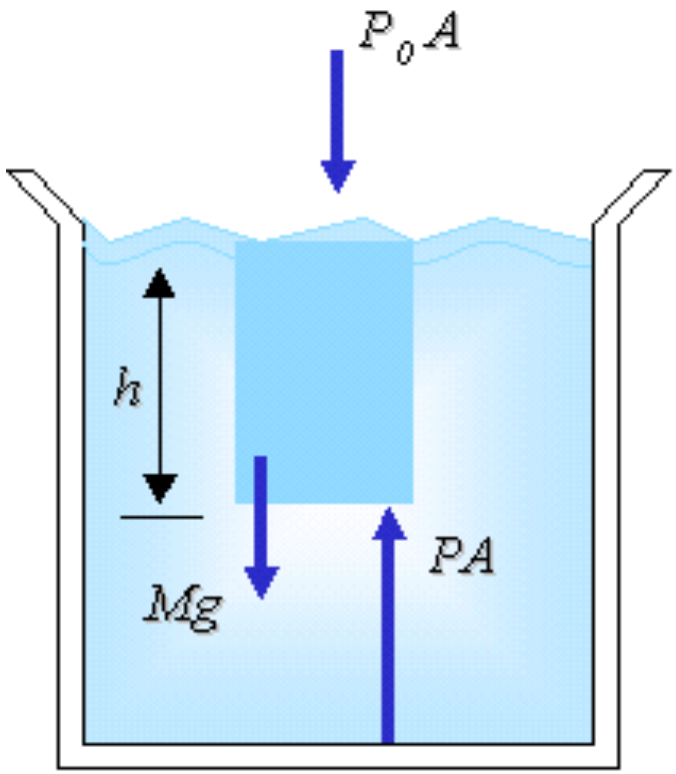
Variation of Pressure with Depth



If the fluid is open to the atmosphere of pressure ,

the pressure of the fluid at a depth is given by:

$$P = P_0 + \rho\, g\, h$$



ρ is the fluid density.

g is the acceleration of gravity.

P_0 is the atmospheric pressure & is usually

$$P_0 = 1.01 \times 10^5\ Pa$$

The pressure in a fluid changes linearly with depth.

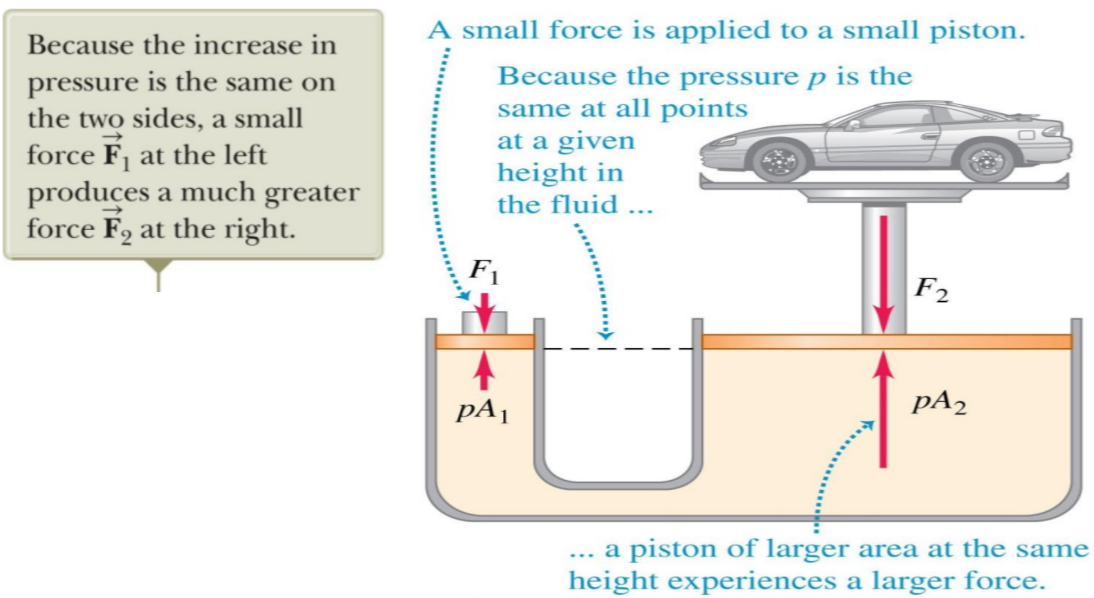
Pascal's principle:

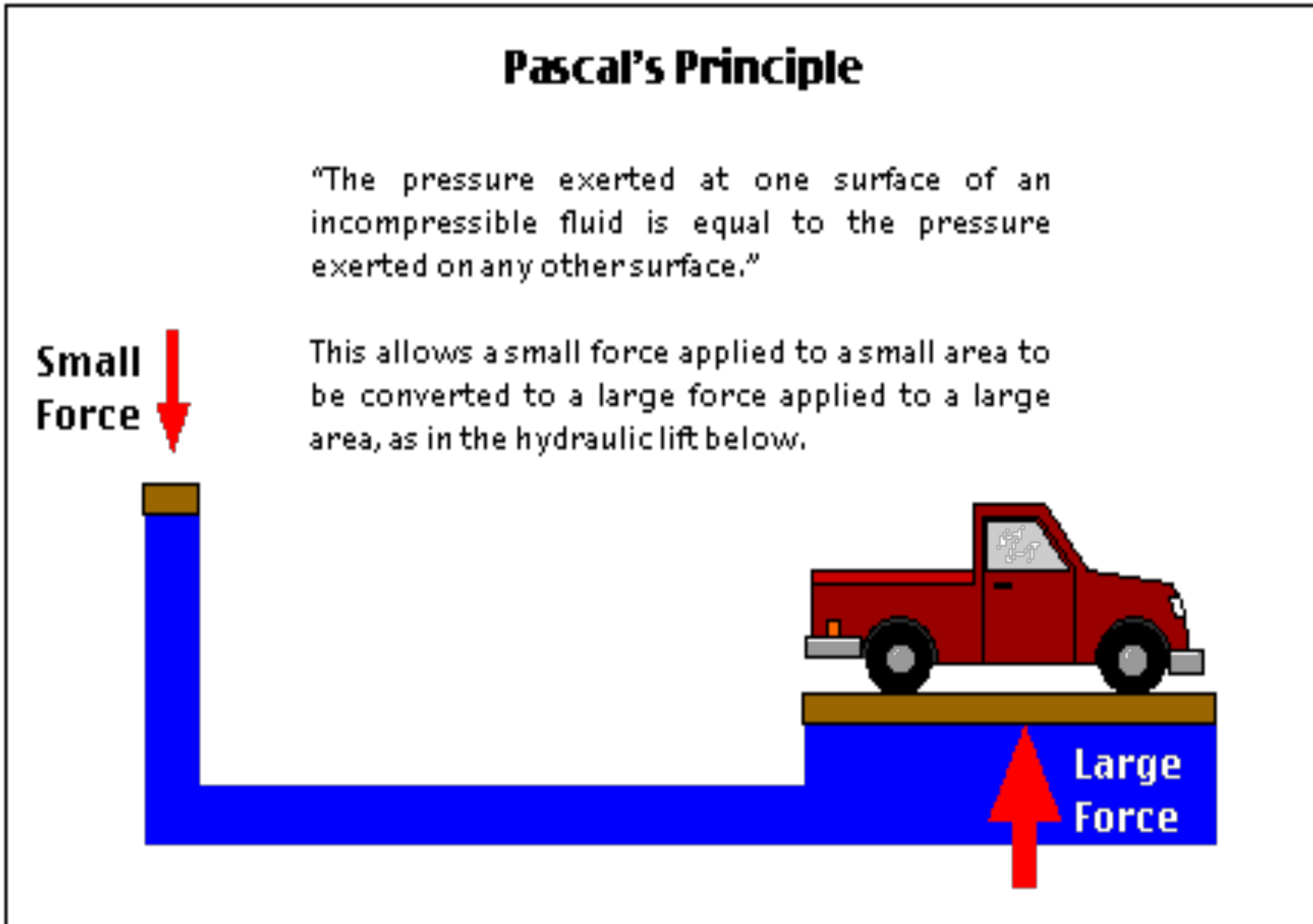
" A change in the pressure applied to an enclosed liquid is transmitted undiminished to every point of the liquid and to the walls of the container. "

In the case of hydraulic press, if the force at one piston of area A_1 is F_1 , this pressure is transmitted through a liquid to the other piston of area A_2 . This produces a force F_2 at the other piston. Since the pressure is the same at both pistons, this gives:

$$P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$F_2 = \frac{A_2}{A_1} F_1$$




Pascal's Principle
"The pressure exerted at one surface of an incompressible fluid is equal to the pressure exerted on any other surface."
This allows a small force applied to a small area to be converted to a large force applied to a large area, as in the hydraulic lift below.
Small Force
Large Force

Example: The Car Lift

In a car lift used in a service station, compressed air exerts force on a small piston that has a circular cross section and a radius of 5.00 cm. This pressure is transmitted by a liquid to a piston that has a radius of 15.0 cm. What force must the compressed air exert to lift a car weighing 13300 N? What air pressure produces this forces?

PRESSURE MEASUREMENTS

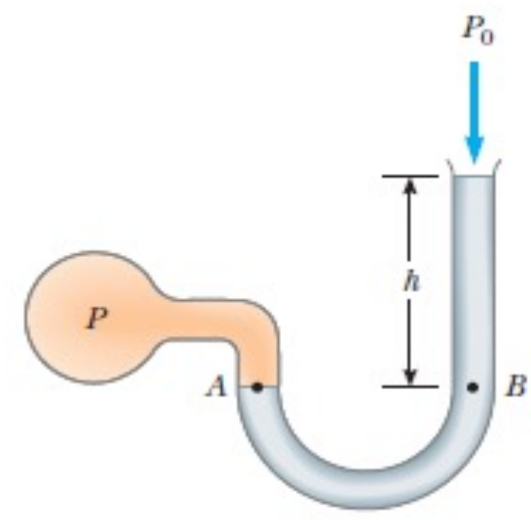
1- MANOMETER

A simple device for measuring pressure is the open-tube manometer. One end of a U-shaped tube containing a liquid is open to the atmosphere, and the other end is connected to a system of unknown pressure *P*.

The pressure at* point *B equals

$$P_0 + \rho g h$$

The pressure at B, however, equals the pressure at A, which is also the unknown pressure P. We conclude that

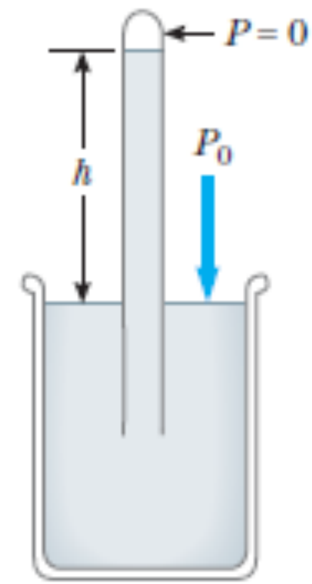


$$P = P_0 + \rho g h.$$

PRESSURE MEASUREMENTS

2- BAROMETER

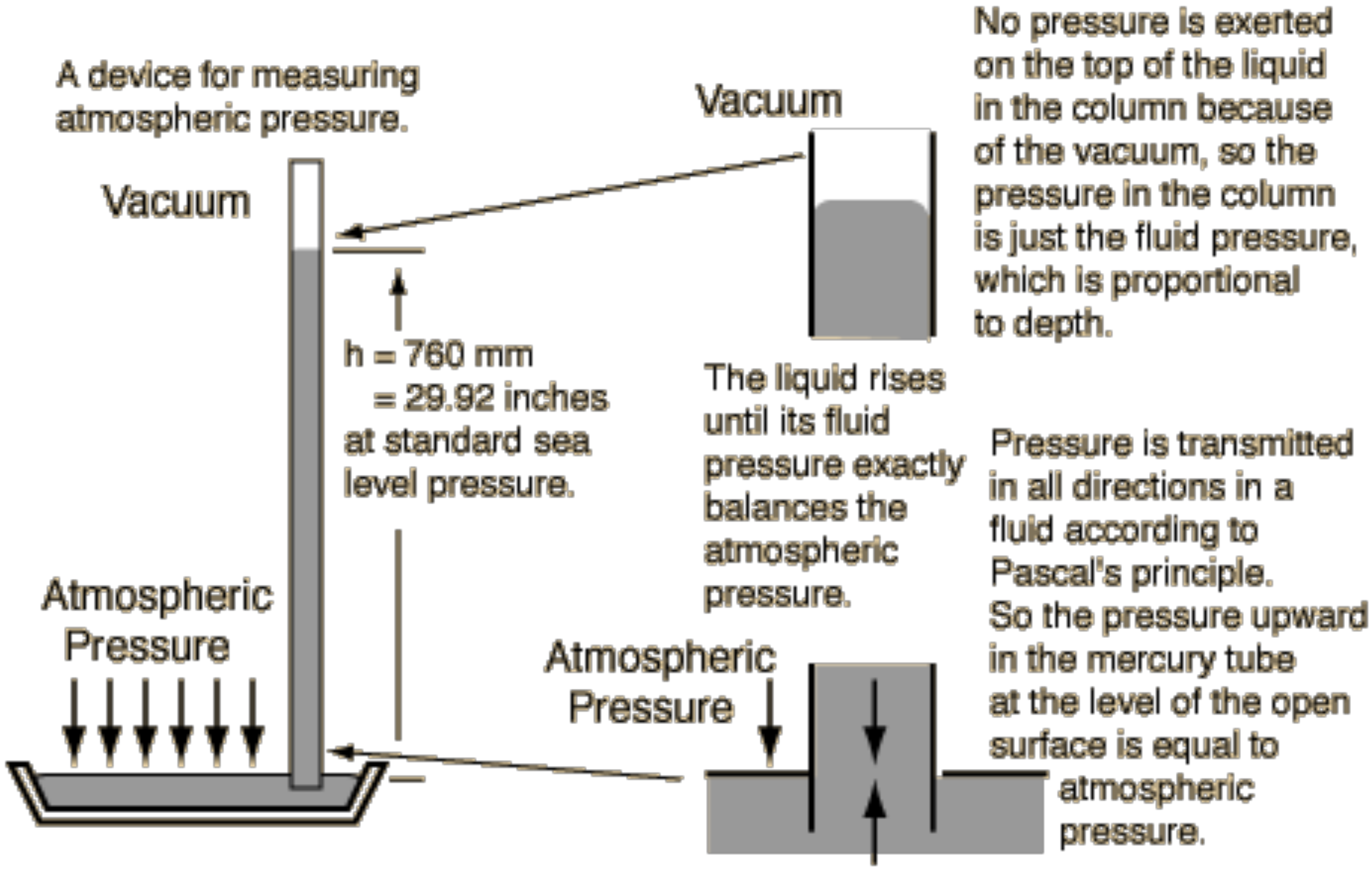
A long tube closed at one end is filled with mercury and then inverted into a dish of mercury. The closed end of the tube is nearly a vacuum, so its pressure can be taken to be zero. It follows that



(b)

$$P_0 = \rho g h$$

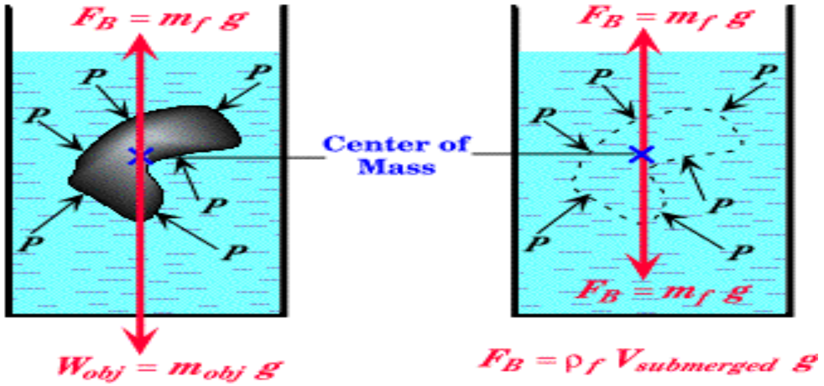
Note that the barometer measures the pressure of the atmosphere, however, the manometer measures pressure in an enclosed fluid.

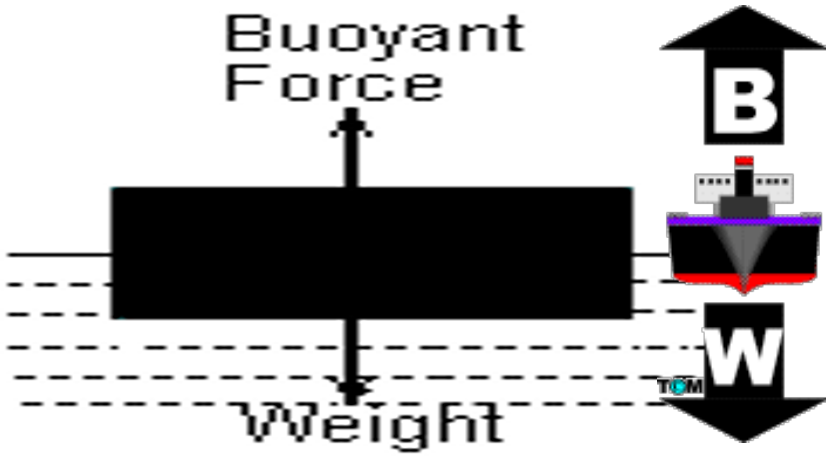

A device for measuring
atmospheric pressure.
Vacuum
h = 760 mm
= 29.92 inches
at standard sea
level pressure.
Atmospheric
Pressure
Vacuum
No pressure is exerted
on the top of the liquid
in the column because
of the vacuum, so the
pressure in the column
is just the fluid pressure,
which is proportional
to depth.
The liquid rises
until its fluid
pressure exactly
balances the
atmospheric
pressure.
Pressure is transmitted
in all directions in a
fluid according to
Pascal's principle.
So the pressure upward
in the mercury tube
at the level of the open
surface is equal to
atmospheric
pressure.
Atmospheric
Pressure

Buoyant Forces

The behavior of an object submerged in a fluid is governed by *Archimedes Principle*. Archimedes determined that a body which is completely or partially submerged in a fluid experiences an upward force called the **Buoyant Force, *B***, which is equal in magnitude to the weight of the fluid displaced by the object.

This principle can be used to explain why ships, loaded with millions of kilograms of cargo, are able to float.





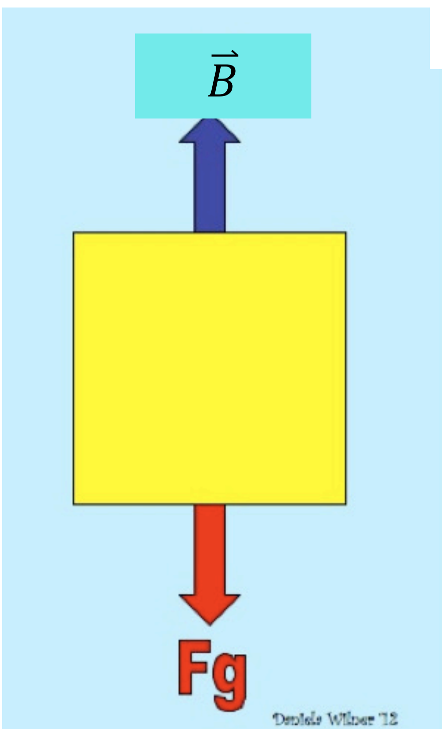
Buoyant force = weight $\Rightarrow$ the object floats and stationary

Buoyant force > weight $\Rightarrow$ the object moves up

Buoyant force < weight $\Rightarrow$ the object moves down

Archimedes's principle :

The buoyant force is equal to the weight of the replaced liquid or gas.



$\vec{B}$ Buoyant Force

&

Fg = Weight = Mass * Gravity

$\vec{B}$ = **Fg**

Fnet = $\vec{B}$ - Fg

Fnet = 0

⇩

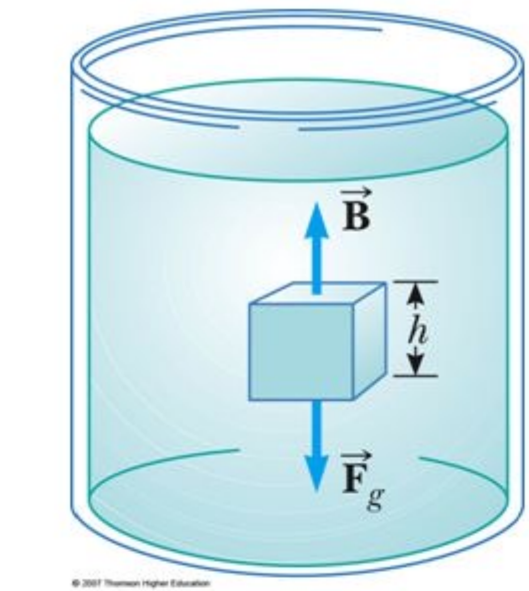
NO Net force

⇩

Since F = m*a,
NO Acceleration

⇩

Block DOESN'T MOVE



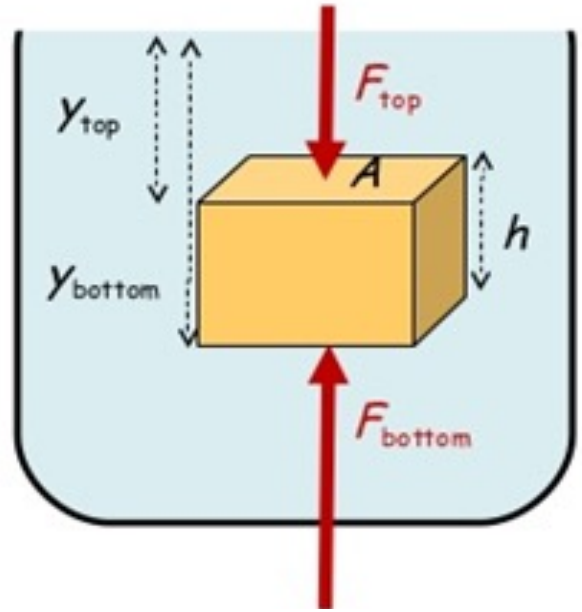
Buoyancy and the Archimedes' principle

A box of base *A* and height *h* is submerged in a liquid of density ρ.

Net force by liquid:

$$\Sigma F = F_{bottom} - F_{top}$$

The buoyant force on the cube is the resultant of the forces exerted on its top and bottom faces by the liquid.



Buoyant force(B)=ΣF, $where, F = PA$

$$B = (P_{bot} - P_{top}) A_{submerged}$$

$$= (\rho_{fluid} g h) A$$

$$= \rho_{fluid} g V_{submerged} = V\rho g = Mg = W$$

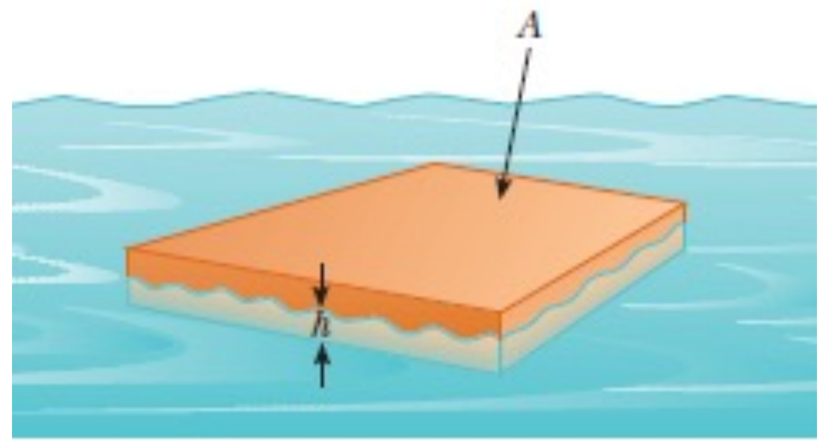
V is volume of water or fluid displaced or volume of object immersed in fluid

Archimedes's principle: The liquid exerts a net force upward called buoyant force whose magnitude is equal to the weight of the displaced liquid.

Example: Floating Down The River

A raft is constructed of wood having a density of $6\times10^{2}\,kg/m^{3}$ .Its surface area is $5.7m^{2}$, and its volume is $0.6m^{3}$. When the raft is placed in fresh water as in Fig.

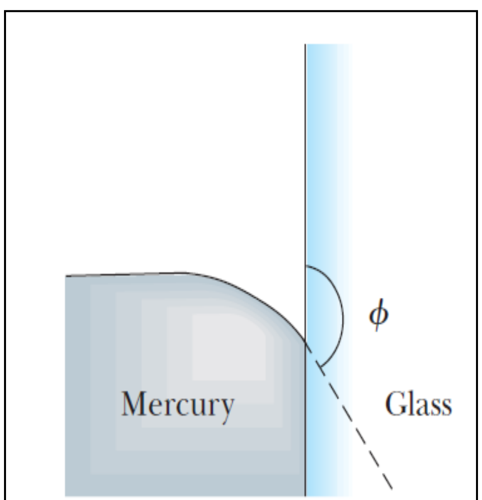
To what depth h is the bottom of the raft submerged?

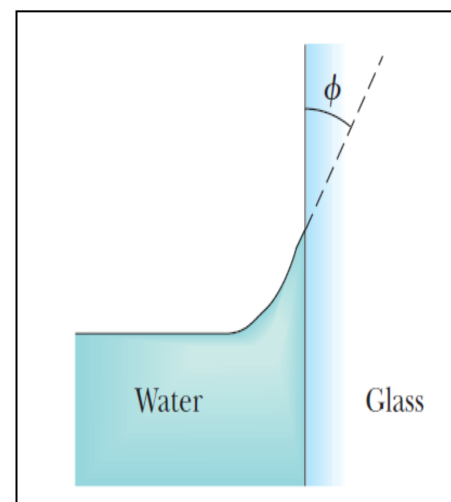


The Surface of Liquid

In general terms, forces between like molecules, such as the forces between water molecules, are called cohesive forces.

and forces between unlike molecules, such as those exerted by glass on water, are called adhesive forces.

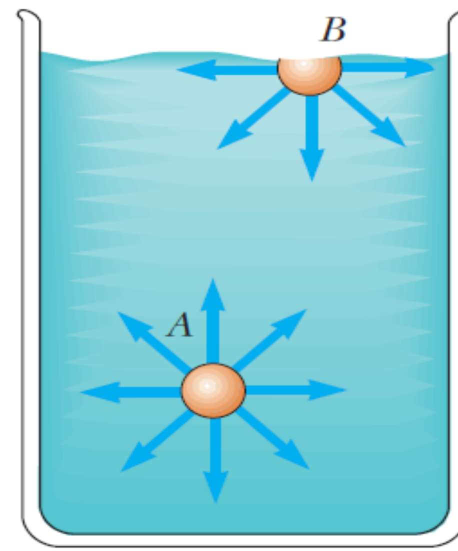




SURFACE TENSION

The drop takes spherical shape because of a property of liquid surfaces called **surface tension**.

The net effect of the pull on all the surface molecules is to make the surface of the liquid contract and, consequently, to make the surface area of the liquid as small as possible.

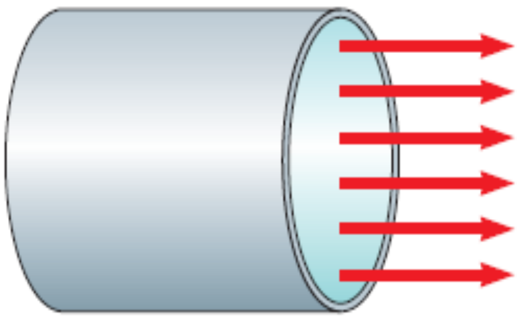


Drops of water take on a spherical shape because a sphere has the smallest surface area for a given volume.

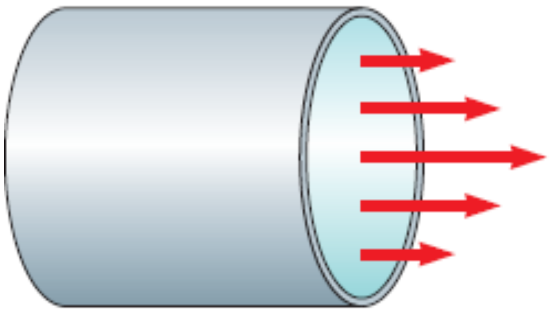
Viscous Fluid Flow

Viscosity refers to the internal friction of a fluid.

- When nonviscous fluid (an ideal fluid) flows through a pipe, the fluid layers slide past one another with no resistance. If the pipe has a uniform cross section, each layer has the same velocity.

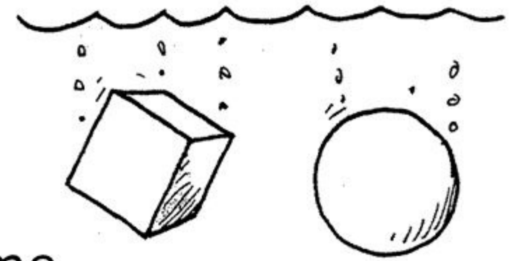


- When a viscous fluid flows through a pipe,the fluid layers have different velocities. The fluid has the greatest velocity at the center of the pipe, whereas the layer next to the wall doesn’t move because of adhesive forces between molecules and the wall surface.



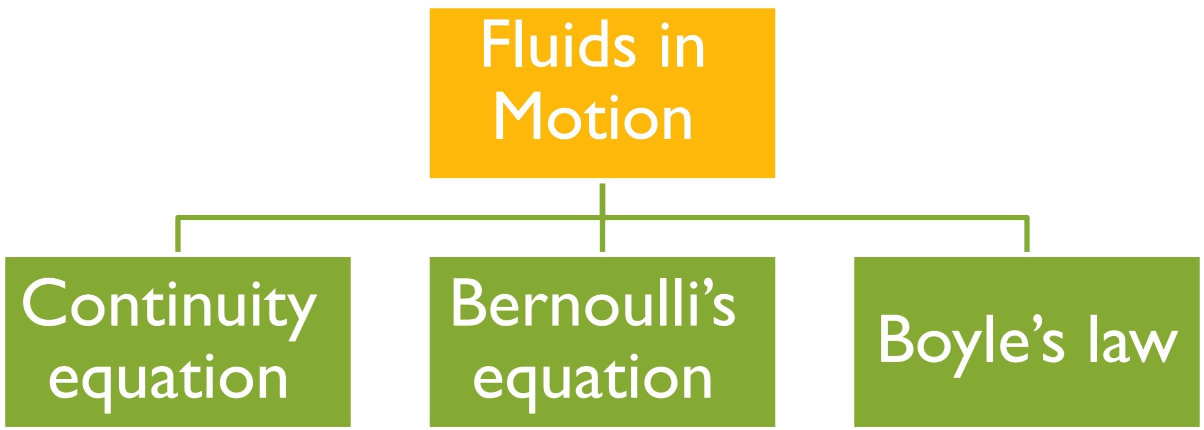
DISCUSSION:

Consider a solid brass cube and a solid brass sphere that have *equal surface areas*. When both are completely submerged in water, the one experiencing the greater buoyant force is the



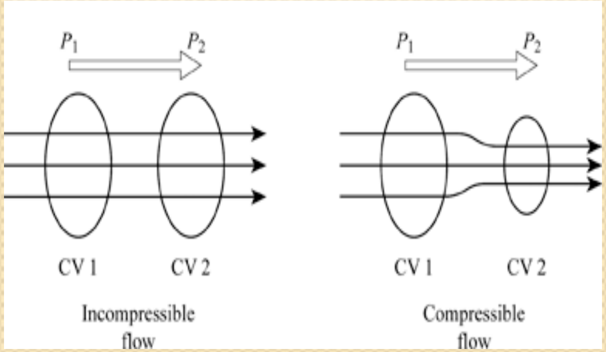
1. cube.
2. **sphere.** ✔
3. … both the same.
4. … not enough information to say.

Fluid Dynamics



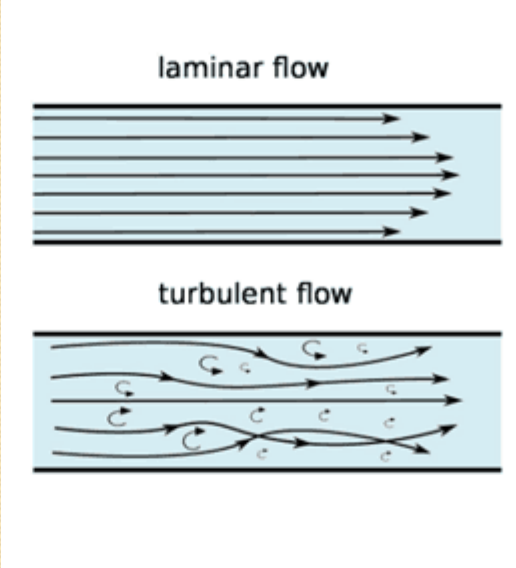
Many features of fluid motion can be understood by considering the behavior of an ideal fluid, which satisfies the following conditions:

1- The fluid is nonviscous, which means there is no internal friction force between adjacent layers.



2. The fluid is incompressible, which means its **density is constant**.

3. The fluid motion is steady, meaning that, all particles passing through a point have the same velocity. **(velocity = cst)**

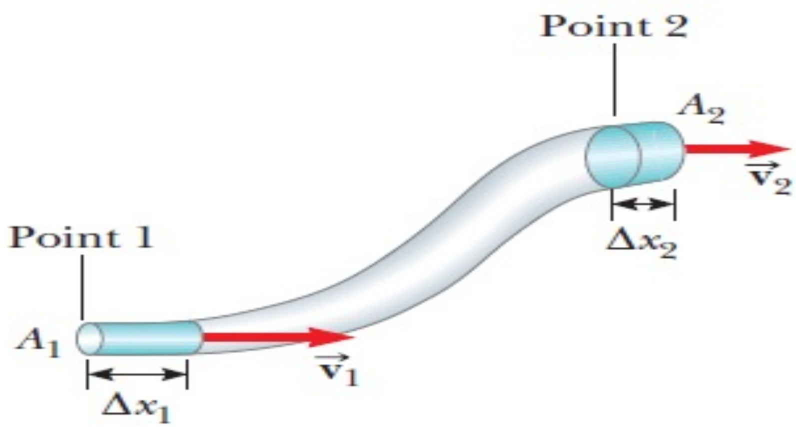


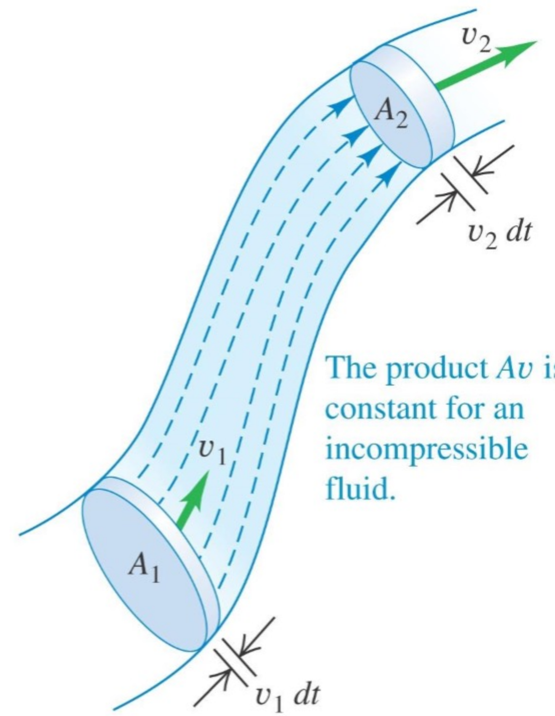
4. The fluid moves without turbulence. This implies that each element of the fluid has zero angular velocity about its center, so there can't be any eddy currents present in the moving fluid. A small wheel placed in the fluid would translate but not rotate. **(Fluid is irrotational)**

Ideal Fluid Assumptions:

- The fluid is nonviscous.
- The flow is steady.(v = const.)
- The fluid is incompressible.
  (ρ = const.)
- The flow is irrotational.

Equation of Continuity



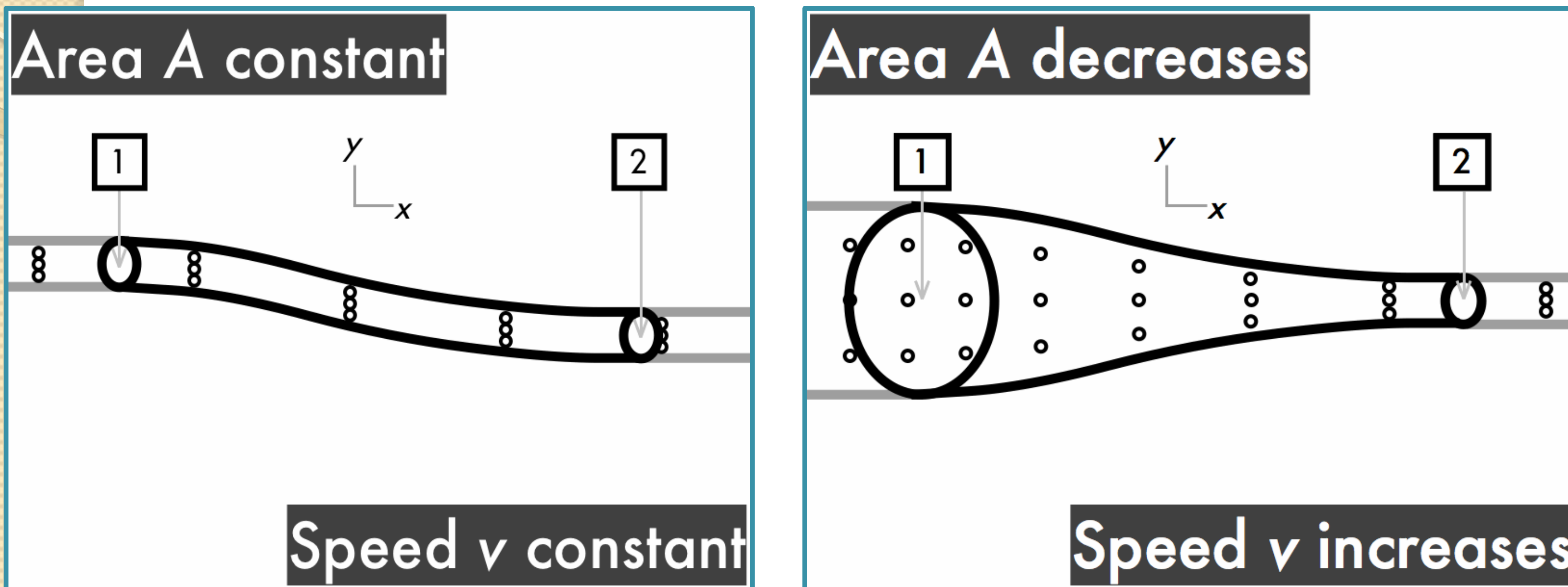


The equation of continuity for fluids states that:

> The product of the area and the fluid speed at all points along a pipe is constant for an incompressible fluid.

$$A_1 v_1 = A_2 v_2 = const.$$

Equation of Continuity



$$A_1 \upsilon_1 = A_2 \upsilon_2 = const.$$

Bernoulli's Equation

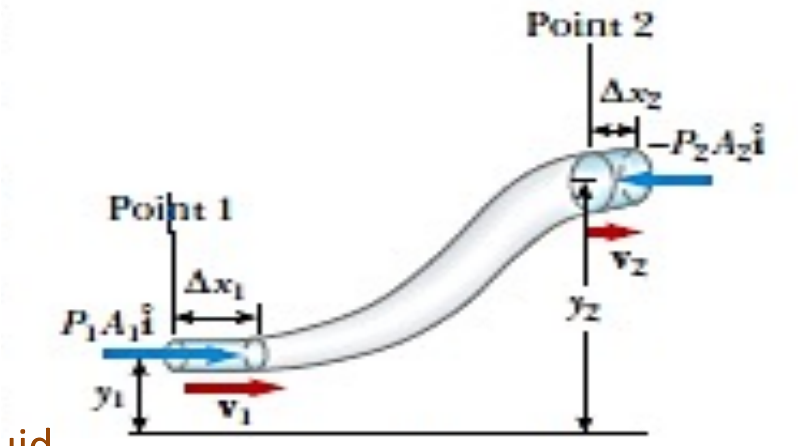
The relationship between fluid speed, pressure, and elevation was first derived by the Swiss physicist Daniel Bernoulli.

The Bernoulli's equation is often expressed as:

$$P + \frac{1}{2} \rho v^2 + \rho g h = \text{constant}$$

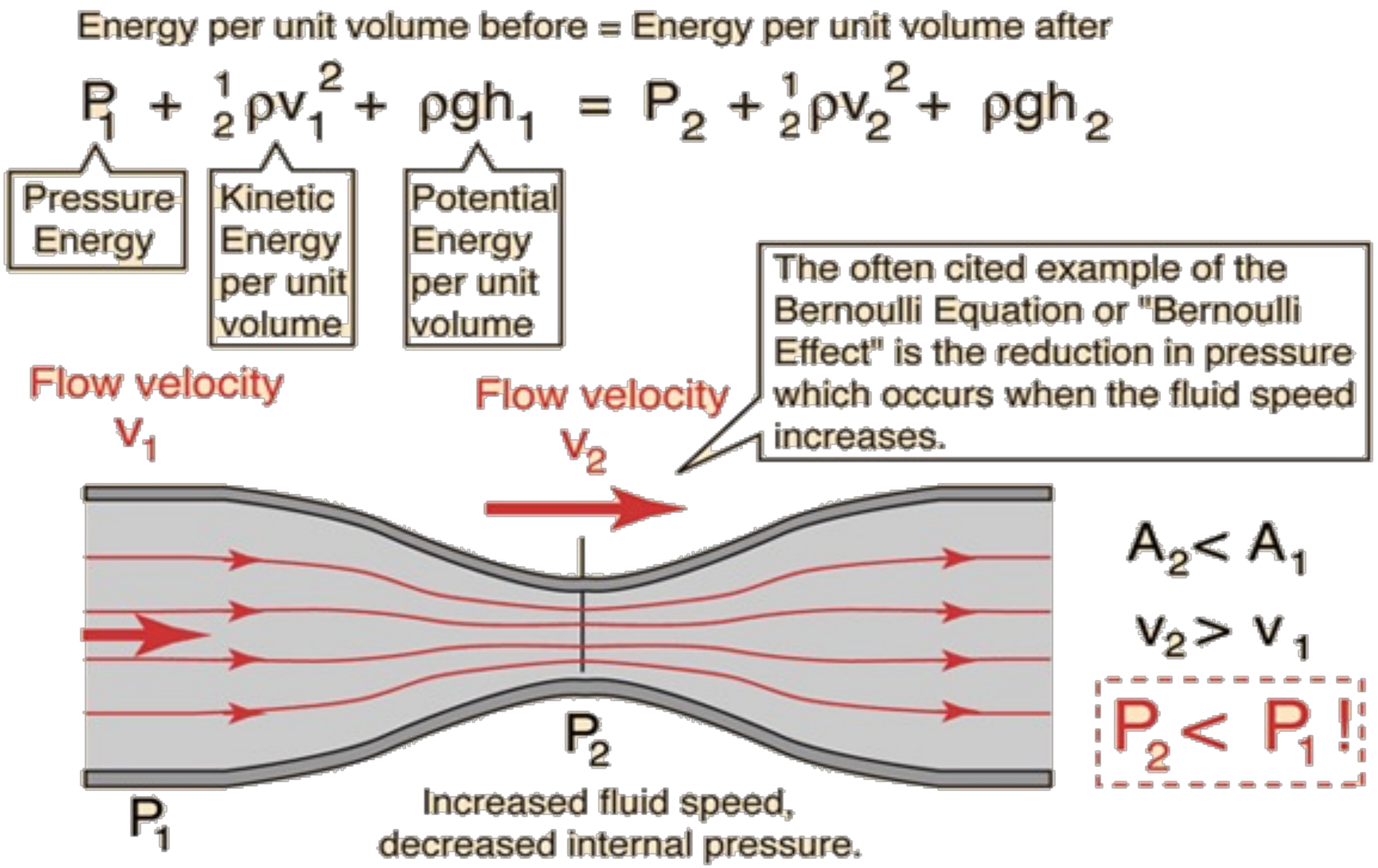
Where P is the pressure, ρ is the density, v is the velocity, h is the elevation, and g is the gravitational acceleration.

where
- points 1 and 2 lie on a streamline,
- the fluid has constant density,
- the flow is steady, and
- there is no friction.



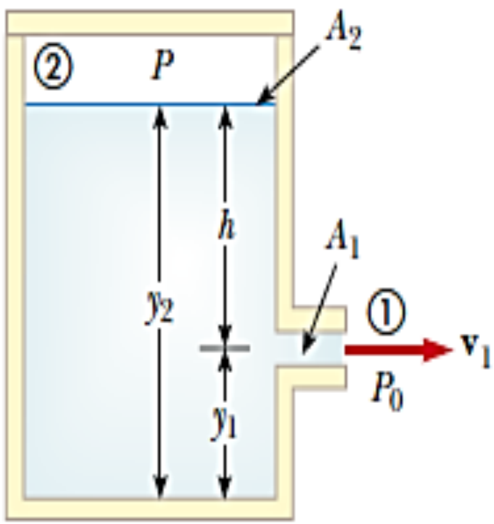
*** This expression shows that the pressure of a fluid decreases as the speed of the fluid increases.
In addition, the pressure decreases as the elevation increases.

Bernoulli's Equation

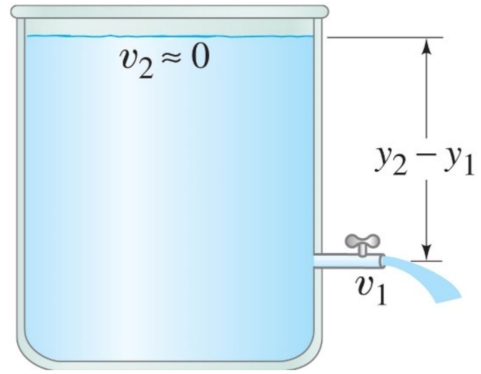


Torricelli's Law

Torricelli's law, also known as **Torricelli's theorem**, is relating the speed of fluid flowing out of an opening to the height of fluid above the opening.



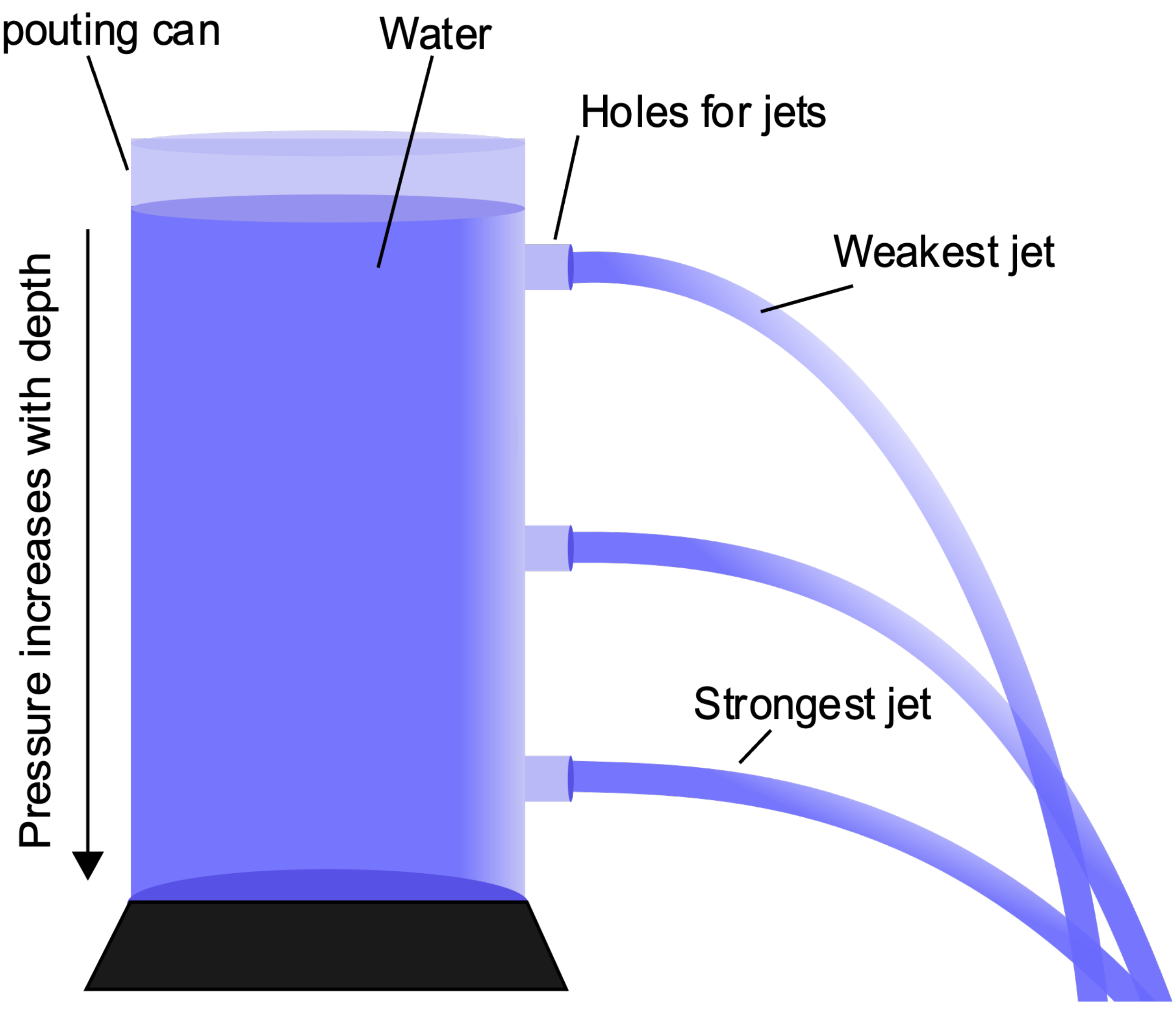
If the tank is open to the atmosphere, then $P = P_0$ and $\mathbf{v_1 = \sqrt{2gh}}$. In other words, for an open tank, the speed of liquid coming out through a hole with a distance h below the surface is equal to the speed acquired by an object falling freely through a vertical distance h.



This phenomenon is known as Torricelli's law.

Torricelli's Law

$$v = \sqrt{2gh}$$



WHAT IS BOYLE'S LAW?

Boyle's Law is one of the laws in physics that concern the behaviour of gases

When a gas is under pressure it takes up less space:

The higher the pressure, the smaller the volume

Boyles Law tells us about the relationship between the volume of a gas and its pressure at a constant temperature

The law states that **pressure is inversely proportional to the volume**

How can we write Boyle's Law as a formula?

- Pressure is inversely proportional to the volume and can be written as:
- **Pressure α 1/volume**

P= pressure in N/m^2

V= volume in m^3 (litres)

k= constant

- This is more usually written as:
- **Pressure = $\frac{\text{constant}}{\text{volume}}$**
- **PV=k**
- **$P_1V_1=P_2V_2$**

P – V graph:

If we plot volume directly against pressure we would get a downwards curve showing that volume gets smaller as the pressure gets larger, and vice versa.