Ambo IBSBS School

Grade 12

Physics Short Note

U - 3

Fluid Mechanics

Introduction to Fluid Mechanics

- Matter most commonly exists as solids, liquids, or gases.
  - ✓ Both liquids and gases are **fluids:** they can flow and deform under applied forces.
- Fluid Mechanics: The study of **fluids** (liquids and gases) in motion and at rest.
- Applications: Mechanical and aerodynamic engineering, biological systems, etc.

Fluid Statics

- ✓ deals with **fluids at rest**, both liquids (hydrostatics) and gases (aerostatics).
- ✓ only normal stress (pressure) is considered, caused by the fluid's weight.
- ✓ *Applications: hydraulic systems, submerged bodies, water dams, etc.*

Properties of Solids, Liquids, and Gases

Brainstorming Questions

Compare solids, liquids and gases in terms of

solid, liquid & gases.mp4

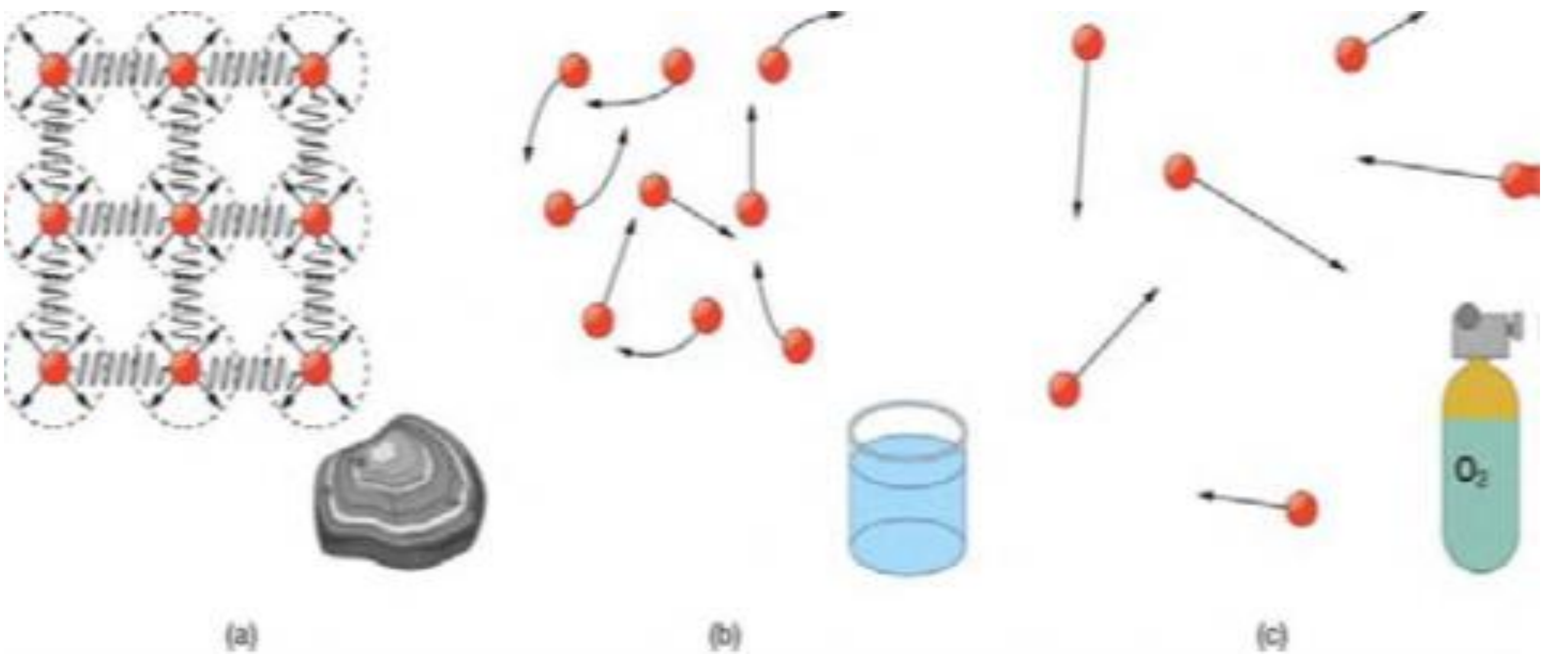
i) their arrangement of particles

ii) forces between the particles

iii) empty space between the particles and

iv) speed of the particles

- **Solids**: Atoms are closely packed, resist deformation and compression due to strong intermolecular forces.
- **Liquids**: Atoms are close but can move, flow, and resist compression due to cohesive forces.
- **Gases**: Atoms are far apart, flow freely, and are easily compressible.

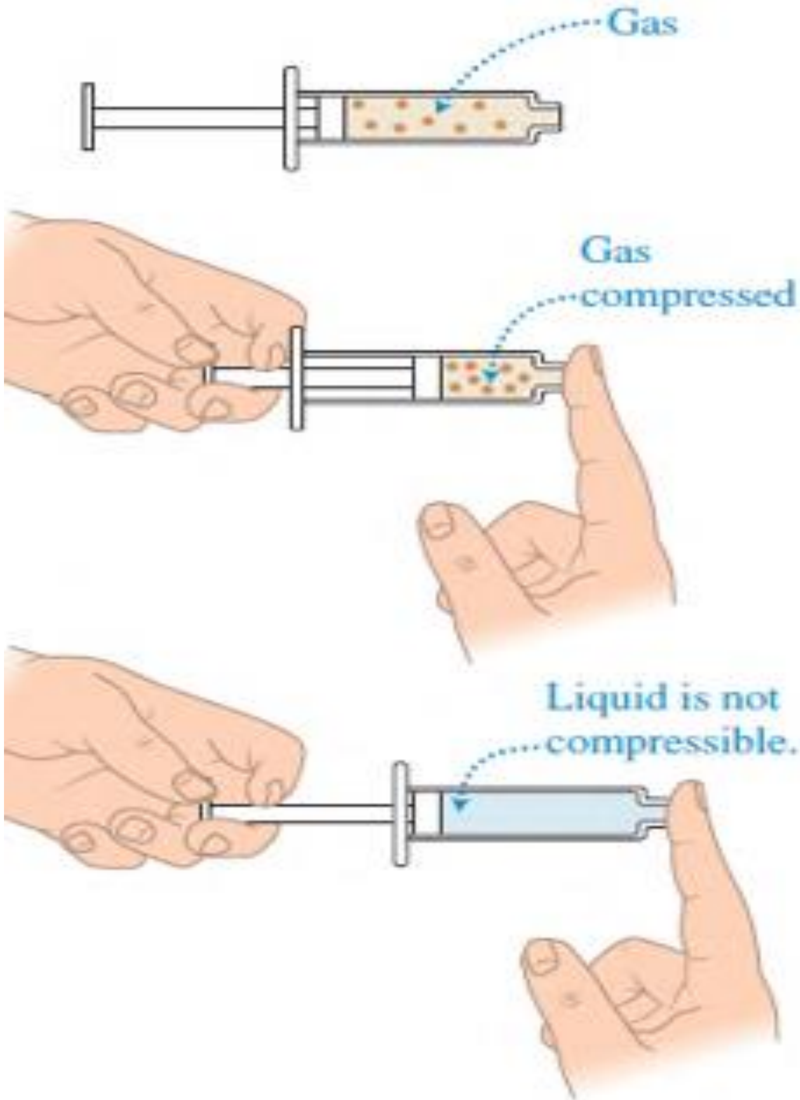


Question!: Why Gases Are Easy to Compress?

- **Solids**: Atoms are in fixed positions, strong forces prevent movement and compression.
- **Liquids**: Atoms can move but are still closely packed, resist compression due to cohesive forces.
- **Gases**: Atoms are widely spaced, weak forces between them, easy to compress due to large spaces between molecules.

Activity: Compressibility of Water and Air

- ✓ Use syringes to observe that air compresses easily, but water does not.



(a)

The same gas completely fills a different volume.

(b)

The liquid volume remains the same regardless of the container.

Important point:

- **Solids** have a fixed shape and volume; **liquids** have a fixed volume but take the shape of the container; **gases** have neither a fixed shape nor volume.

Pressure in Fluid

Brainstorming Questions

1. What do you think pressure means in everyday life?
2. What is the difference between pressure and stress?
3. Can you think of examples where pressure is involved?
4. How do you think pressure affects our daily activities?

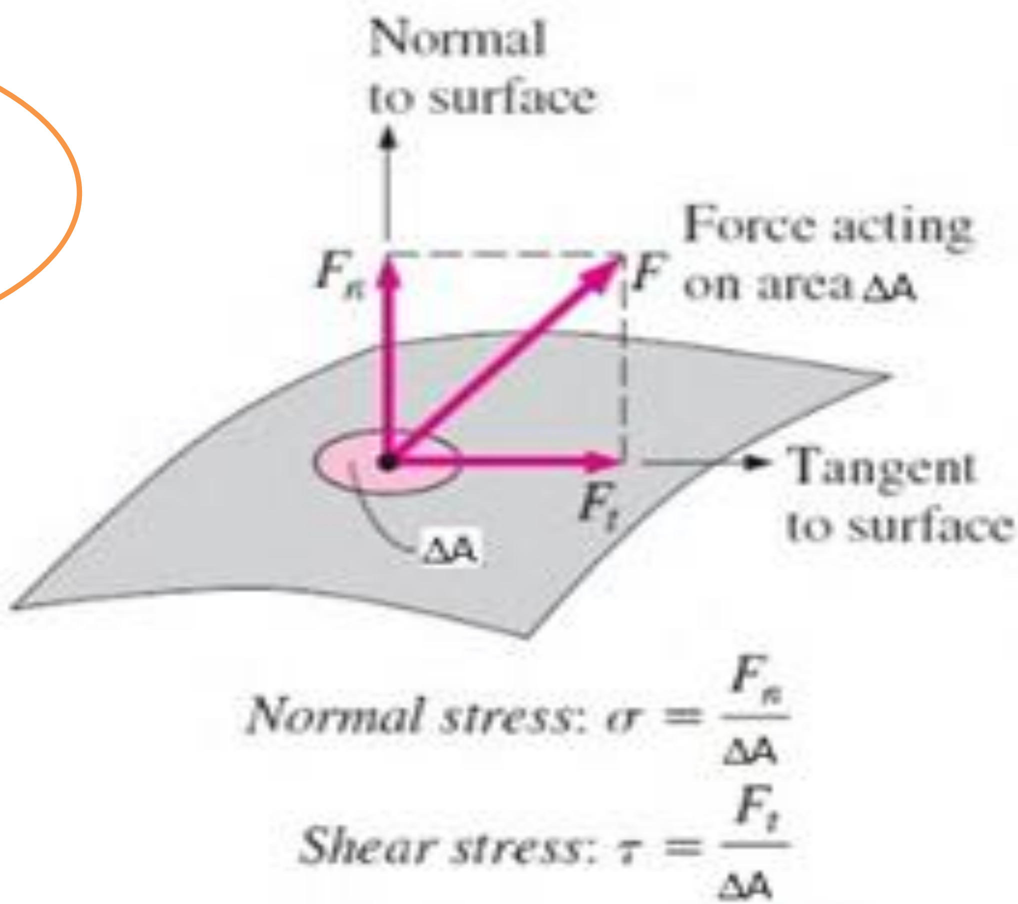
Concept of stress 3d animation.mp4

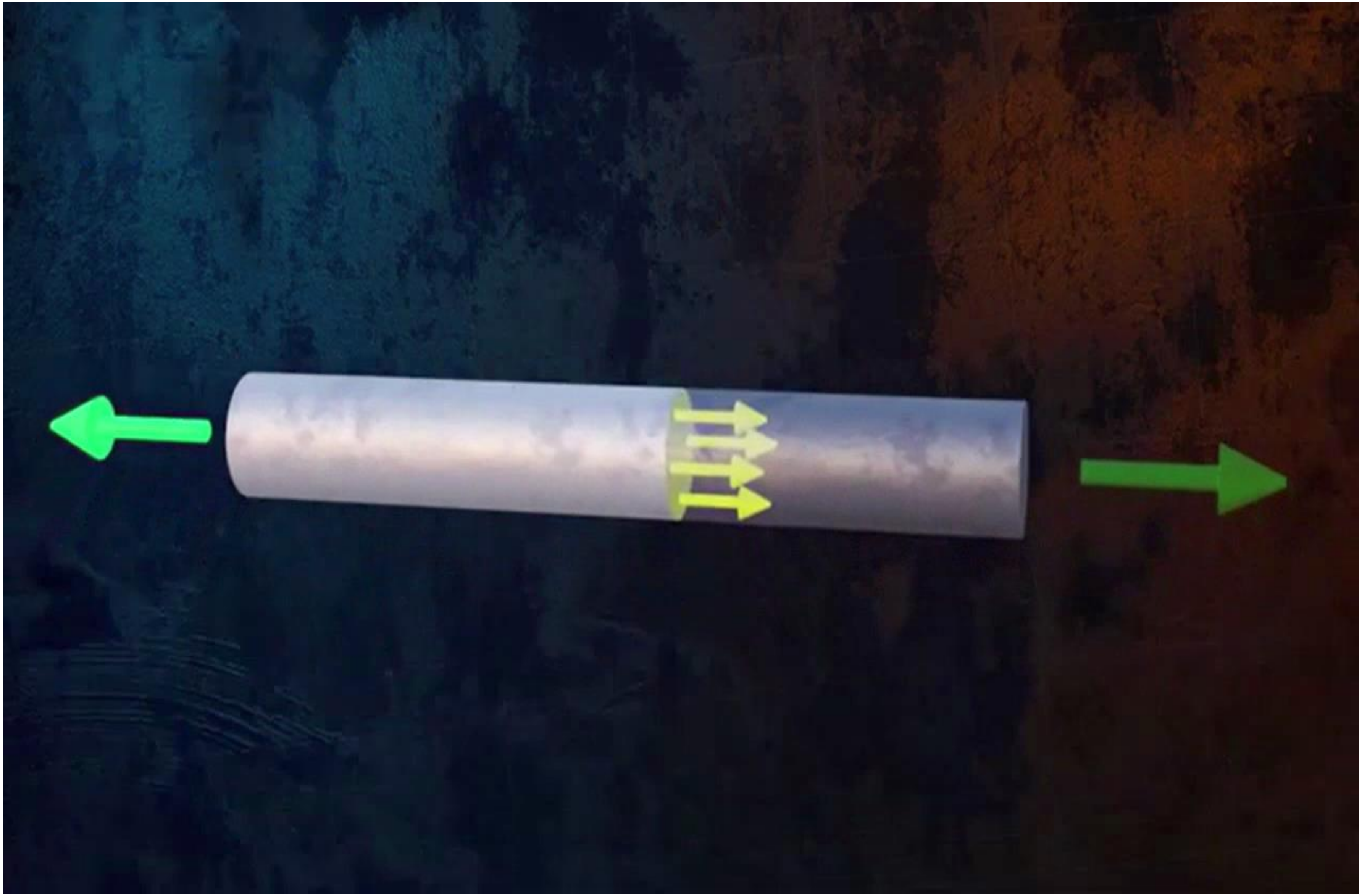
- **Pressure** is defined as a normal force exerted by a fluid (or a solid) per unit area.
  - ✓ It can be seen as a form of stress when considering the force acting within the fluids.
- **Stress** is defined as the internal force applied per unit area with in the materials.
  - ✓ It quantifies how much internal force is distributed over a given area when an external force is applied.
  - ✓ *It can be normal stress or shear stress.*
    - The normal component of a force acting on a surface per unit area is called the normal stress.
    - The tangential component of a force acting on a surface per unit area is called shear stress.

❖ For fluid at rest, the shear stress is zero and the only existing stress is the normal stress and is called **pressure**.

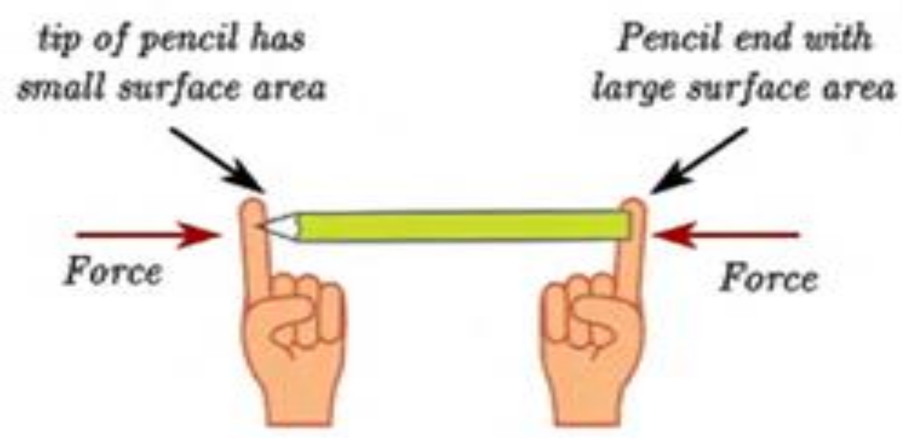
If F is the magnitude of the force exerted on the fluid (or solid) at a particular point and A is the surface area at which this force is applied, the pressure P at this particular point is given by:

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





- **Pressure** is a **scalar quantity** because it is proportional to the magnitude of the force.
- If a large force acts on a small area, the pressure is large.



Effect of force is more when contact area is small

Activity !

Draw the pressure versus area graph for constant force and pressure versus force graph for constant Area.

- The unit of pressure is N/m^2 - pascal (Pa)

  $1pa = 1N/m^2$

- Other units of pressure are: millimeter mercury (mmHg), torr, atmosphere (atm), pounds per square inch (psi), etc

1atm = 760mmHg = 760torr = 101.3K Pa = 14.7psi

Example

1. As a woman walks, her entire weight is momentarily placed on one of her shoes.
   (a) Calculate the pressure exerted on the floor by the shoe if it has an average width 10 cm and average length of 30cm and the woman's mass is 60.0 kg.
   (b)Express the pressure in atm, torr, mmHg and psi.

2. Nail tips exert tremendous pressures when they are hit by hammers because they exert a large force over a small area. What force must be exerted on a nail with a circular tip of 1mm diameter to create a pressure of $3 \times 10^9 \frac{N}{m^2}$?

Pressure in Gases

- Gas particles exert pressure whether or not a solid object is present.
- Pressure is the result of many particle collisions acting on a surface.

Resistance in Balloon:

- ✓ Air inside a balloon resists crushing due to gas particles colliding with the balloon's walls.

  These collisions create an outward force that pushes back on your fingers.

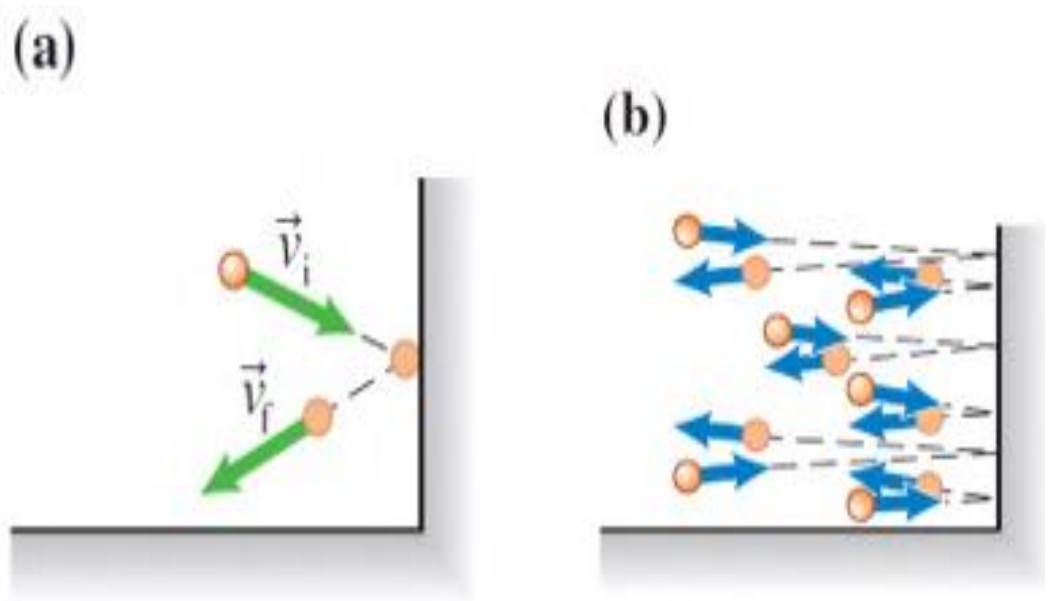
Formation of Pressure:

- ✓ Gas particles move randomly and collide with solid surfaces.
- ✓ Each collision exerts an impulsive force, similar to a tennis ball hitting a wall.

When many particles collide at a constant rate, a constant force is exerted on the surface.

For example: Effect of Blowing a Balloon:

- ✓ Adding more air increases the number of particles colliding with the balloon's surface.
- ✓ Increased collisions cause greater outward force, expanding the balloon.



- The actual pressure at a given position is called the absolute pressure.
  - ✓ It is measured relative to absolute vacuum (i.e., absolute zero pressure).
- The difference between the absolute pressure and the local atmospheric pressure is called the gauge pressure (P_{gauge}).
  - ✓ It can be positive or negative.
  - ✓ If pressure is below atmospheric pressure, it is sometimes called vacuum pressures and are measured by vacuum gauges.
- Absolute, gauge, and atmospheric pressures are related to each other by:

$$P_{guage} = P_{abs} - P_{atm}$$

$$P_{vac} = P_{atm} - P_{abs}$$

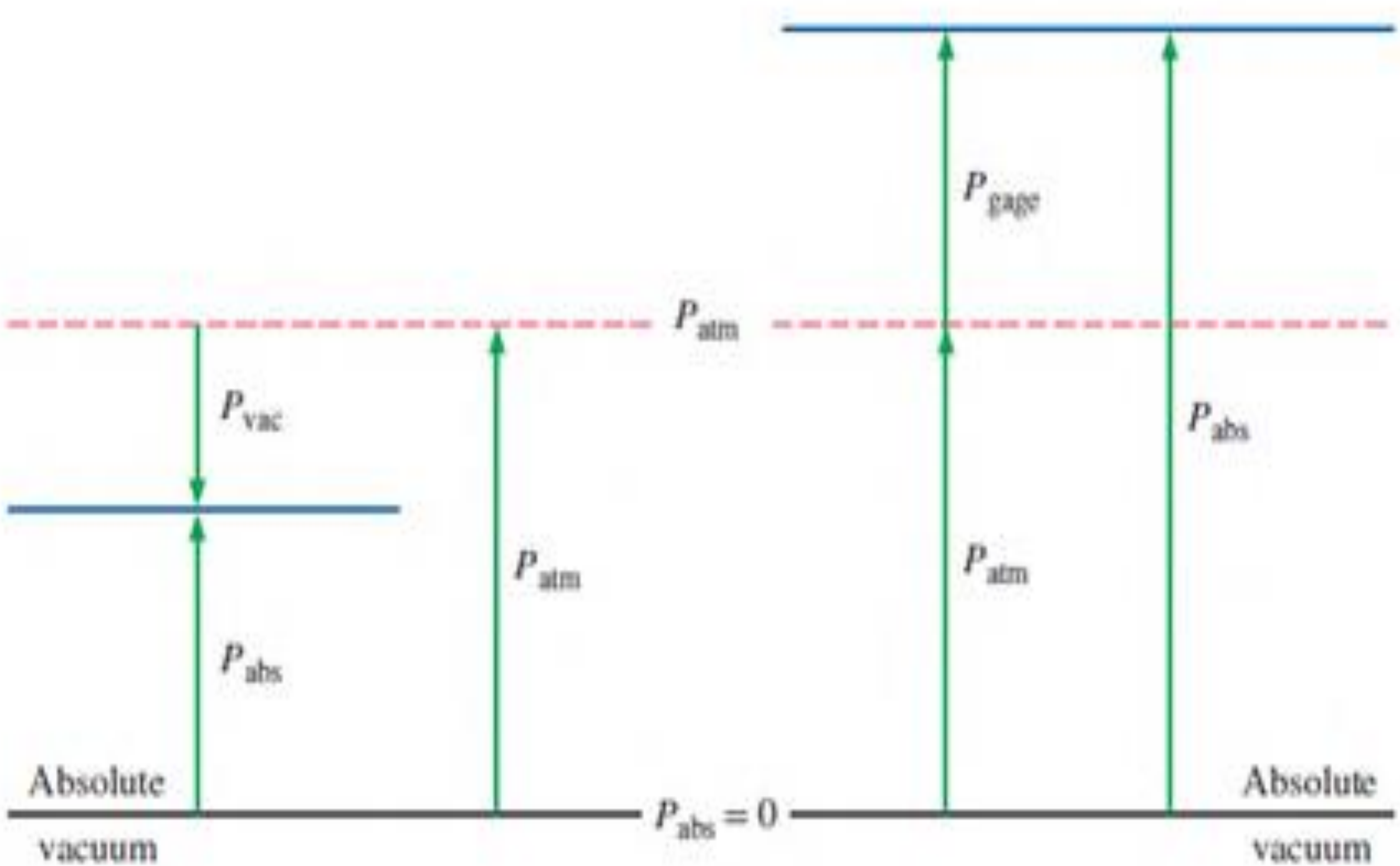


Figure: Absolute, gauge, and vacuum pressures.

For example

- If the gauge used to measure the air pressure in an automobile tire reads 32.0 psi;
  - ✓ it indicates a pressure of 32.0 psi above the atmospheric pressure.
  - ✓ at a location the atmospheric pressure is 14.3 psi, the absolute pressure in the tire is 32.0 + 14.3 = 46.3 psi.

Examples

1. A vacuum guage connected to a chamber reads 5.8 psi at a location where the atmospheric pressure is 14.5 psi. Determine the absolute pressure in the chamber.
2. The absolute pressure in water at a depth of 8 m is read to be 175 kPa. Determine the local atmospheric pressure.

Density of Substances: Understanding the concept of density and its applications

Brainstorming Questions

1. Meet Mr. Cotton and Mr. Iron, who are cube-shaped, with each side measuring 1 cm, giving them both a volume of 1 cc. Mr. Cotton is light, while Mr. Iron is heavy, even though they are the same size.

   i. Why is Mr. Iron heavier than Mr. Cotton if they are the same size?

   ii. How do we calculate density using mass and volume?

   iii. What does density tell us about the materials Mr. Cotton and Mr. Iron are made from?

2. Think about why can boats float when they are made out of material that is denser than water?

Density (ρ)

- ✓ is the mass per unit volume of a substance

$$\rho = \frac{m}{V}$$

Where; m is mass and V is volume

- ✓ SI unit: kg/m^3; Also measured in g/cm^3

$$1\,g/cm^3 = 1000\,kg/m^3$$

Note

- ➢ Density tells us how heavy an object is for its size.
- ➢ The same volume of different substances can have different density.

For example: 2 g of cotton & 8 g of Iron of the same volume have different density.

Density and Matter

- Solids: High density (molecules packed tightly)
- Liquids: Lower density than solids
- Gases: Lowest density due to spread-out molecules

Applications of Density

- **Hot air Balloon:** density of air inside a balloon is less than the surrounding cooler air.
- Floating & Sinking: Lower density objects float, higher density objects sink.
- Buoyancy: Based on density differences.
- Gold panning: denser gold settle at the bottom while lighter ones wash away.
- Material Identification: Each material has a unique density.

https://phet.colorado.edu/en/simulations/density

https://phet.colorado.edu/sims/html/density/latest/density_en.html

- Density directly affects pressure of fluids (liquid & gases).
- Density measures the mass of one cubic meter of a substance.

For example, at sea level and 0 °C*:*

- the mass of { $1.0\ m^3$ of air is 1.3 kg ⟶ $1.3\ kg/m^3$.
  $2.0\ m^3$ of air is 2.6 kg ⟶ $1.3\ kg/m^3$.

- The density of most gases is proportional to pressure and inversely proportional to temperature.
- Liquids and solids(incompressible substances), the variation of their density with pressure is usually negligible.

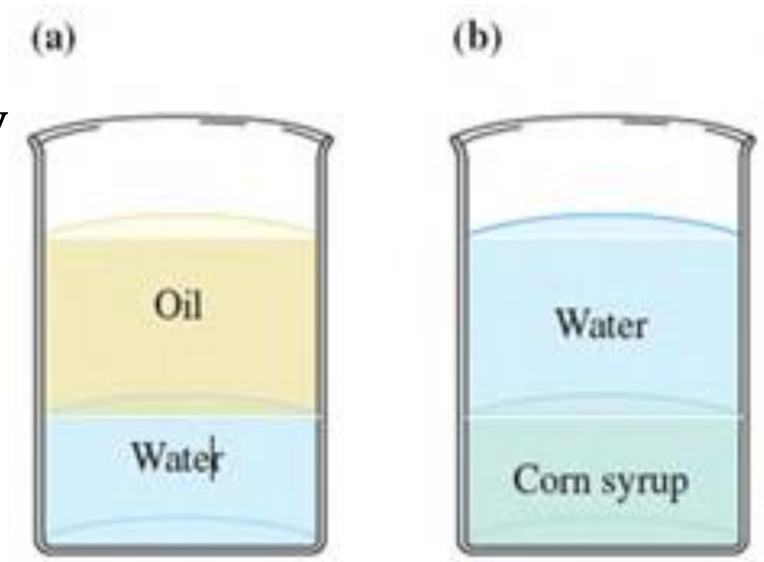
Examples

1. An iron ball with radius 5.0 cm has a mass of 2.0 kg. Determine the ball's density.

2. When three non-miscible liquids with densities $\rho_1 < \rho_2 < \rho_3$ are mixed together, which liquid will be at the top, middle and bottom layer?

Important points

- Independently of which fluid is poured first the layer of oil is always on top of the water, b/c the density of oil is less that the density of water.
- Layer of water is always on top of the corn syrup, b/c the density of water is less that the density Corn syrup.



Helium vs Air Balloons:

- Helium balloons rise; air filled balloons fall.
  - ✓ *Helium atoms are lighter than air molecules.*

Explain !

Density and compression:

- Gases at the same temp. and pressure have the same concentration ⇨ (Avogadro's Law)

$$\rho = \left(\frac{n}{V}\right) M$$

  - ✓ Helium has lower density due to its lower mass (4 g/mol) compared to air molecules (av.29 g/mol)
- Air filled Balloons is more denser than air.
  - ✓ *Balloon rubber is denser than air.*
- Gas compression slightly increases density for both air and helium.

Table Densities of some common substance at standard temperature (0°C) and pressure (1 atm)

Substance	$\rho\ (kg/m^3)$	substance	$\rho(kg/m^3)$
Air	1.29×10^3	Iron	7.86×10^3
Aluminum	2.70×10^3	Lead	11.3×10^3
Benzene	0.879×10^3	mercury	13.6×10^3
Brass	8.4×10^3	oxygen	1.43
copper	8.92×10^3	nitrogen	1.25
Fresh water	1.00×10^3	Sea water	1.03×10^3
Gold	19.3×10^3	silver	10.5×10^3
Helium gas	1.79×10^{-1}	Tin	7.30×10^3
Hydrogen gas	8.99×10^{-2}	uranium	19.1×10^3
Ice	0.917×10^3		

Specific gravity (S_G)

- is the ratio of a substance's density to a reference (usually density of water at 4°C, $\rho = 1 \text{g/cm}^3$)
- is a dimensionless quantity.

$$S_G = \frac{\rho_{sub}}{\rho_{H_2O}}$$

For example: The specific gravity of mercury at 20 °C is 13.6. Therefore, its density at 20 °C is 13.6 g/cm^3 = 13.6 kg/L = 13,600 kg/m^3.

Note that!

➢ Substances with specific gravities less than 1 are lighter than water, and thus they would float on water (if immiscible).

What is Density_ .mp4

Table: The specific gravity of some substances at 20°C and 1atm unless stated otherwise

Substance	SG	Substance	SG
Air	0.001204	**Seawater**	1.025
Blood (at 37°C)	1.06	**Gasoline**	0.68
Ethyl alcohol	0.790	**mercury**	13.6
Gold	19.3	**bones**	1.7-2.0
Ice (0°C)	0.916		

- Best-known equation in the gas phase that relate density and pressure of gases is the ideal-gas equation of state, expressed as

$$PV = nRT = \frac{mRT}{M}$$

$$P = \frac{m}{V}\frac{R}{M}\mathrm{T} = \rho\frac{R}{M}\mathrm{T}$$

$$\rho = \left(\frac{P}{\left(\frac{R}{M}\right)T}\right)$$

Where;

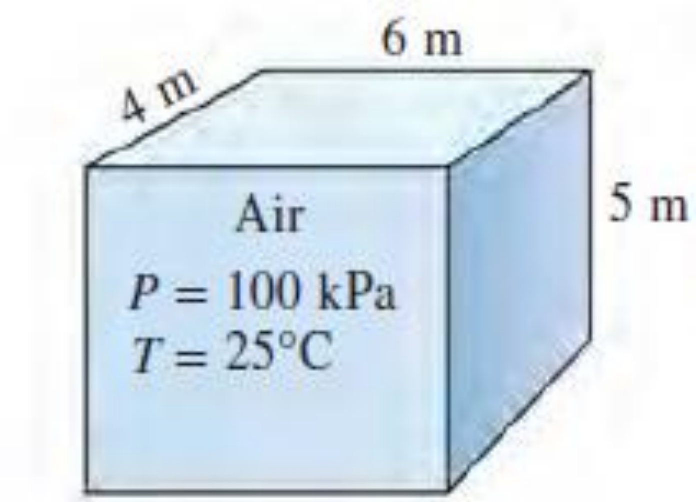
- P is the absolute pressure,
- V is the gas volume,
- T is the thermodynamic (absolute) temperature
- R/M is the gas constant(different for each gas)
- R is the universal gas constant (= 8.314 J/mol.K) and
- M is the molar mass (also called molecular weight) of the gas.

Table: Molar mass, gas constant, and ideal-gas specific heats of some substances

Substance	Molar mass, M, kg/kmol	Gas constant	Substance	Molar mass, M, kg/kmol	Gas constant
Air	28.97	0.2870	Chlorine, Cl_2	70.905	0.1173
Ammonia, NH_3	17.03	0.4882	Fluorine, F_2	38.00	0.2187
Argon, Ar	39.95	0.2081	Helium, He	4.003	2.077
Bromine, Br_2	159.81	0.05202	Hydrogen, H_2	2.016	4.124
Carbon dioxide, CO_2	44.01	0.1889	Nitrogen, N_2	28.01	0.2968
Carbon monoxide, CO	28.01	0.2968	Nitric oxide, NO	30.006	0.2771
Nitrogen dioxide, NO_2	46.006	0.1889	Oxygen, O_2	32.00	0.2598
Sulfur dioxide, SO_2	64.06	0.1298			

Example

1. Determine the density, specific gravity, and mass of the air in a room whose dimensions are 4 m *x* 5 m *x* 6 m at 100 kPa and 25°C.



2. The atmospheric pressure at certain location is 96.6 kpa. determine the absolute pressure at a depth of 8 m in a liquid whose specific gravity is 0.78 at the same location.

3.2 Properties of Pressure in Fluids

- Gas particles in random motion exert pressure on the container walls and objects inside the gas.
- Liquids behave similarly, with particles exerting pressure equally in all directions.

Figure *Arcs of water leaving holes at the same level in a bottle.*

- Pressure increases rapidly underwater due to the higher density of water compared to air.

Pascal’s Law

Definition: *A change in pressure applied to a confined fluid is transmitted undiminished throughout the fluid and its container walls.*

Explanation: Pressure spreads uniformly due to increased molecular collisions, regardless of where it is applied.

Microscopic View of Pascal’s Law

- ✓ When pressure is applied to one part of a fluid, molecules near the surface collide more frequently with their neighbors, spreading the pressure uniformly throughout.

Pascal's Law.mp4

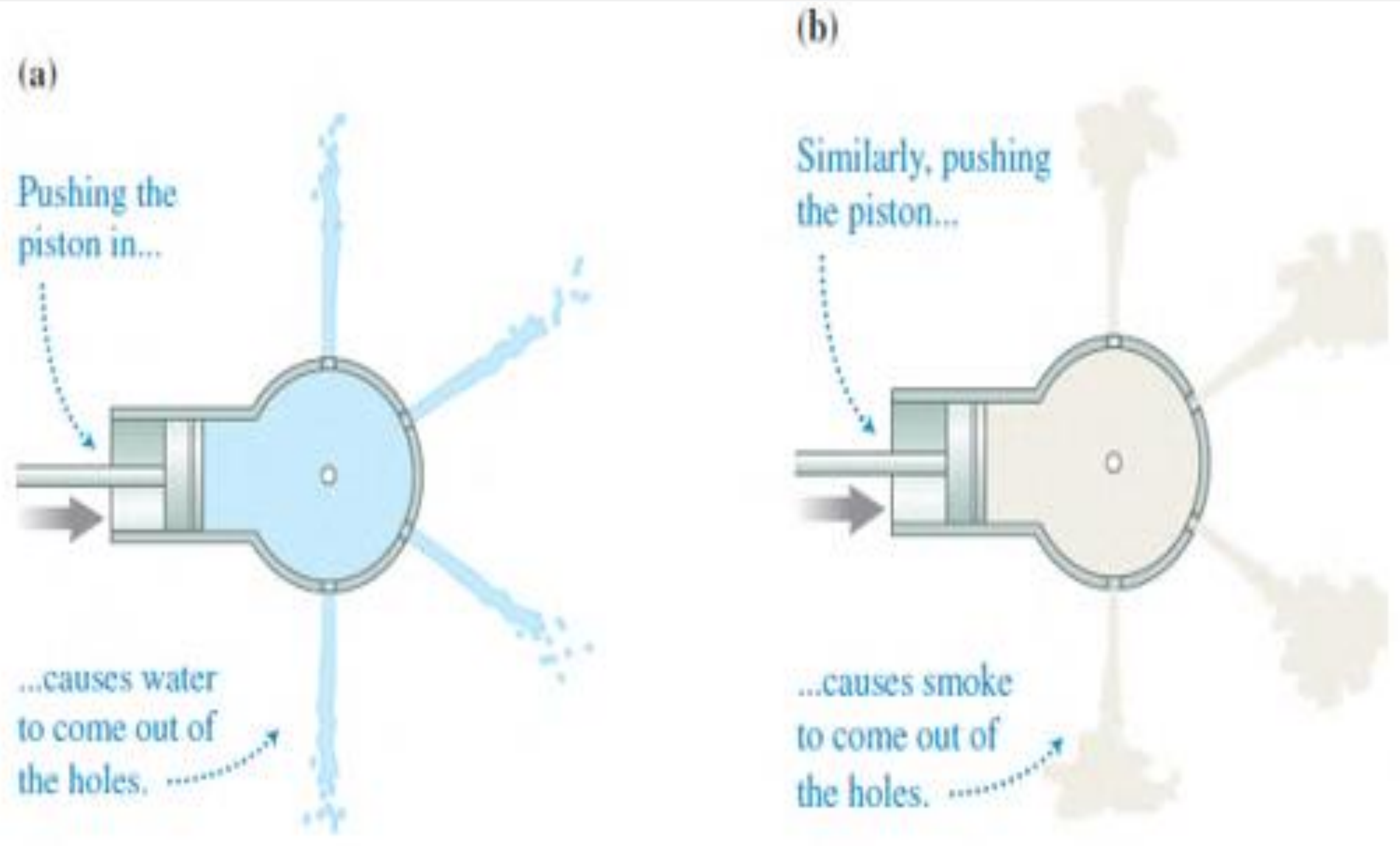


Figure: *Pascal's law: Increasing the pressure of a fluid at one location causes a uniform pressure increase throughout the fluid*

Hydraulic Press (Application of Pascal's Law)

✓ A hydraulic press multiplies force, allowing small forces to lift heavy loads (e.g., in car lifts or hydraulic brakes).

Work Formula: equal work is maintained between pistons.

$$F_1 . d_1 = F_2 . d_2$$

Pressure Formula: equal pressure is produced at all points in the machine.

$$P_1 = P_2$$

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

How a hydraulic jack works (3D Animation .mp4

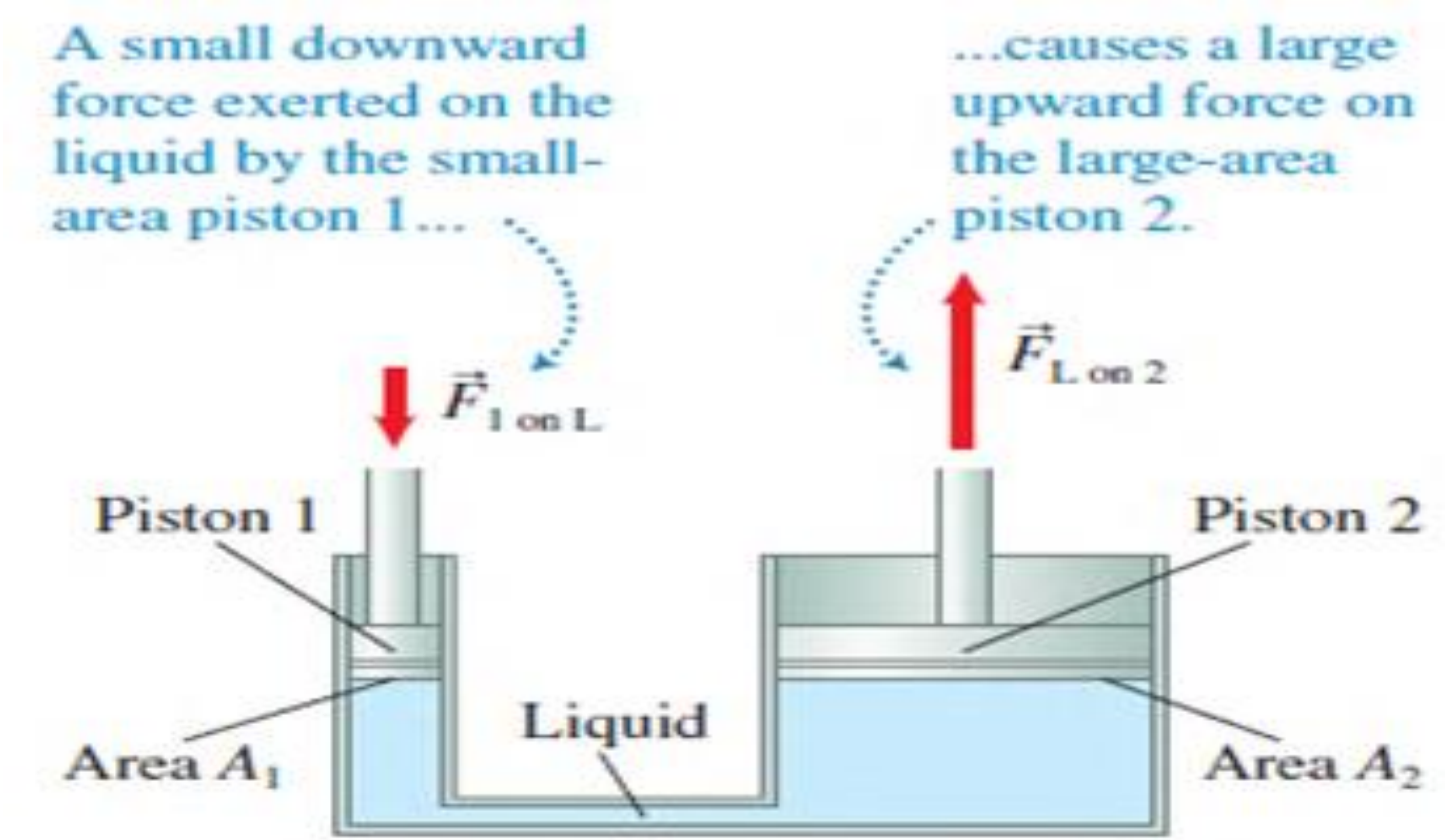


Figure : Schematic of a hydraulic lift.

Examples

A hydraulic lift has a small piston with surface area 0.002 m^2 and a larger piston with surface area 0.2 m^2. Piston 2 and the car placed on piston 2 have a combined mass of 1800 kg. What is the minimal force that piston 1 needs to exert on the fluid to slowly lift the car?

Variation of pressure with depth

Pressure in a Liquid:

- Pressure (P) increases with depth in a liquid.

  Formula: ($P = P_0 + \rho g h$), where:

  - P_0 = Pressure at surface(atmospheric pressure if open)
  - ρ = Density of liquid,
  - g = Gravitational acceleration,
  - h = Depth below surface.
  - ✓ *If the liquid is not open to the atmosphere(closed) and Po is zero and*

$$P = \rho g h$$

- Pressure is the same at equal depths, regardless of the container's shape.

Example

Calculate the force on a circular area of diameter 0.40 m on the bottom of the ocean which is 25.0 m below the surface. Take atmospheric pressure and density of sea water at the bottom to be 1 atm and $1.03 \times 10^3\ kg/m^3$ respectively.

https://phet.colorado.edu/sims/html/under-pressure/latest/under-pressure_en.html

Atmospheric Pressure:

Q. Why a sealed empty water bottle on an airplane collapses as the plane descends from a higher elevation to a lower elevation as shown in Figure below.

(a) at 4,300 m (b) at 2,700 m (c) at 300 m.

- Air pressure decreases with increasing altitude.
  - ✓ *There are two reasons why air pressure decreases as altitude increases: density and depth of the atmosphere.*

Example pressures:

- ✓ Sea level: 101.325 kPa,
- ✓ 1000 m: 89.88 kPa,
- ✓ 5000 m: 54.05 kPa.

Questions

1. Fill a plastic bottle with water and leave until the hot covered plastic water cool down to room temperature. What happens to the plastic bottle? Explain the reason why this happened. Repeat the activity leaving the bottle opened while it is cooling. Do you get the same result? Why?
2. Fill a plastic bottle with water and cover the lid tightly. Make a small hole at the bottom of this water filled and tightly covered plastic bottle by a nail or a pin. Does all the water leave the plastic bottle? Why?

- On top of Mount Everest, air pressure is only about one-third of the pressure at sea level.
- High altitudes affect cooking, engine performance, and breathing due to lower pressure and density.

For example:

Boiling point of water at the Mt. Everest (68°C to 70°C) is less than at sea level(100°C).

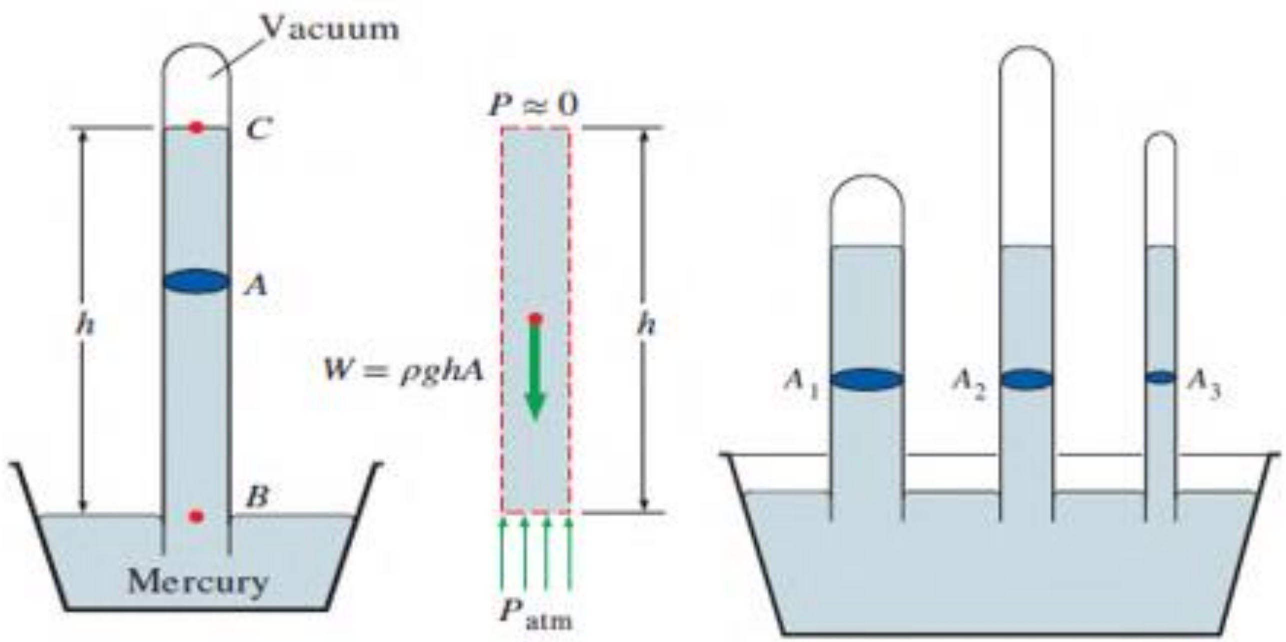
Figure : *At high altitudes, a car engine generates less power and a person gets less oxygen because of the lower density of air.*

Pressure Measurement Devices:

Brain storming!

1. What are some common instruments used to measure fluid pressure, and how do they work?
2. Who was the first to conclusively proved that the atmospheric pressure can be measured by inverting a mercury-filled tube into a mercury container that is open to the atmosphere?
3. What principle this instruments use to measure fluid pressure?

i) **Barometer**: Measures atmospheric pressure (barometric pressure) using a mercury column.



a) b)

The pressure at point ;

- ✓ B is equal to the atmospheric pressure.
- ✓ C can be taken to be zero (relative to P_{atm}), since there is only mercury vapor above point.

Writing a force balance in the vertical direction gives;

$$P_{atm} = \rho g h$$

Note that!

- The length and the cross-sectional area of the tube have no effect on the height of the fluid column of a barometer (b).
- A frequently used pressure unit is the standard atmosphere(atm.): is the pressure produced by a column of mercury 760 mm in height at 0 °C (ρ_{Hg}= 13,595 kg/m^3) under standard gravitational acceleration (g = 9.807 m/s^2).

$$P = \rho_{Hg} gh = 101.325 \text{ KPa} = 760 \text{ torr} = 760 \text{ mmHg} = 1 \text{atm}.$$

Q. What happen if water instead of mercury were used to measure the standard atmospheric pressure?

Answer: a water column rises to about10.3 m or 10300 mm (inconvenient to use).

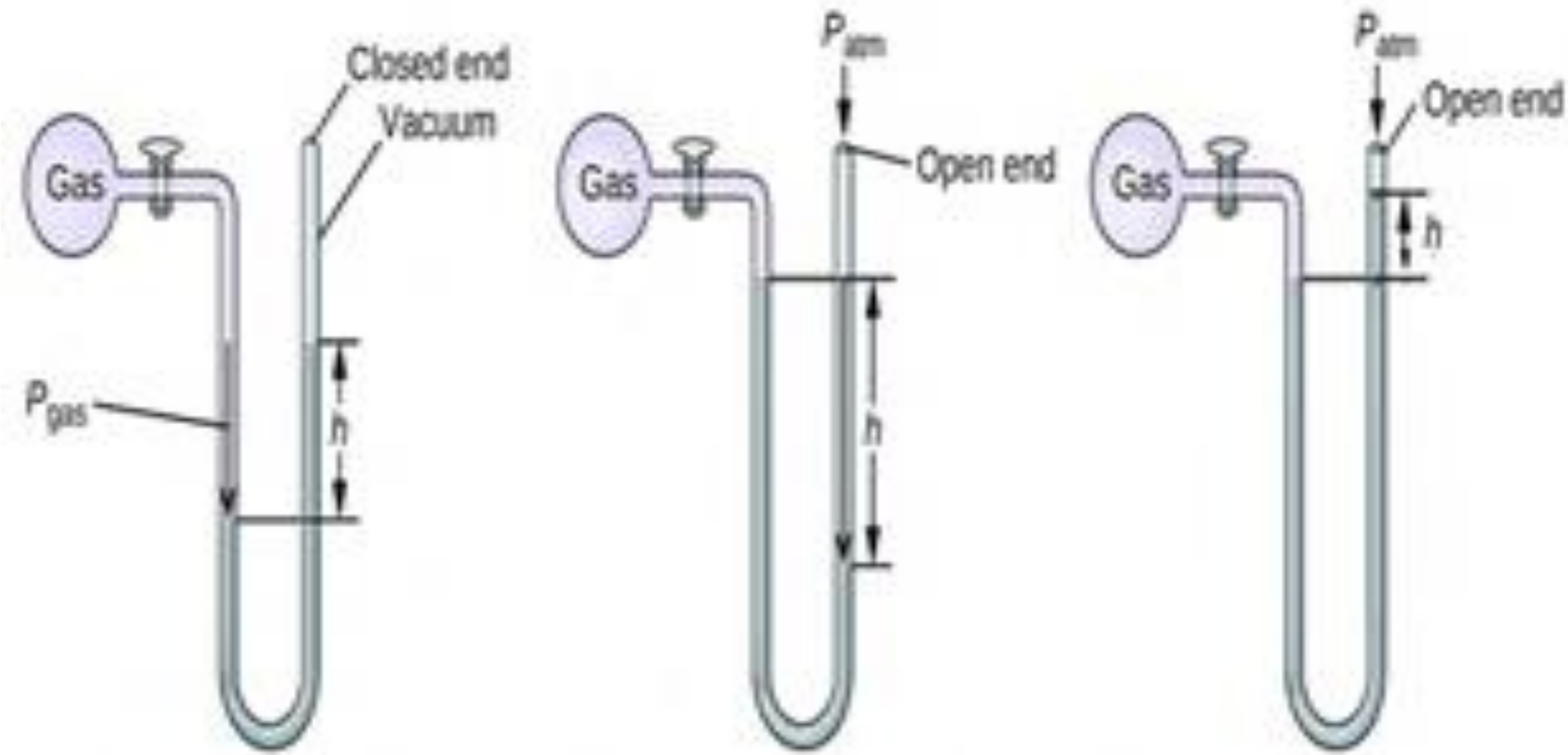
Example

Determine the atmospheric pressure at a location where the barometric reading is 740 mmHg and the gravitational acceleration is $g = 9.805\ m/s^2$. (Assume the temperature of mercury to be 10°C, at which its density is 13,595 kg/m^3).

ii) Manometer: Measures gas pressure in containers; two types:

- Closed-end: Measures trapped gas pressure.
- Open-end: Measures gas pressure relative to atmospheric pressure.

Features	Closed-End manometer	Open-End manometer
End type	One end closed (Vacuum)	One end open to the atmosphere
Measures	Absolute pressure	Gauge pressure
Reference point	Vacuum (No external pressure)	Atmospheric pressure
Typical use	Measuring very low pressures	Measuring gas pressure close to or above atmospheric pressure
Pressure formula	$P_{gas} = \rho gh$	$P_{gas} = P_{atm} \pm \rho gh$



$P_{gas} = \rho g h$ $\quad$ $P_{gas} = P_{atm} - \rho g h$ $\quad$ $P_{gas} = P_{atm} + \rho g h$

VideoTrimmer_The U Tube Manometer lg.mp4

Manometer.mp4

$P_{gas} = \rho g h$ for close end manometer

$P_{gas} = P_{atm} - \rho g h$ for open end manometer with h mercury level below gas connected arm

$P_{gas} = P_{atm} + \rho g h$ for open end manometer with h mercury level above the open arm

- Manometer is mainly used to measure low pressure differences accurately.

Example

An open manometer is used to measure the pressure of a gas in a tank. The fluid used has a specific gravity of 0.85, and the fluid column in the open arm is 55 cm above the gas connected arm. If the local atmospheric pressure is 96 kPa, determine the absolute pressure within the tank.

3.3 Archimedes Principle

i) Buoyant Force:

- ✓ The upward force exerted by a fluid on any submerged object.
- ✓ Caused by pressure differences in the fluid (higher at the bottom, lower at the top).

Buoyancy .mp4

Archimedes' Principle:

"Buoyant force equals the weight of the fluid displaced by the object"

$$F_B = P_2A - P_1A = \rho_f ghA$$

$$F_B = \rho_f gV$$

$$F_B = m_f g$$

$$F_B = W_f$$

What is the Archimedes' Principle_ (1).mp4

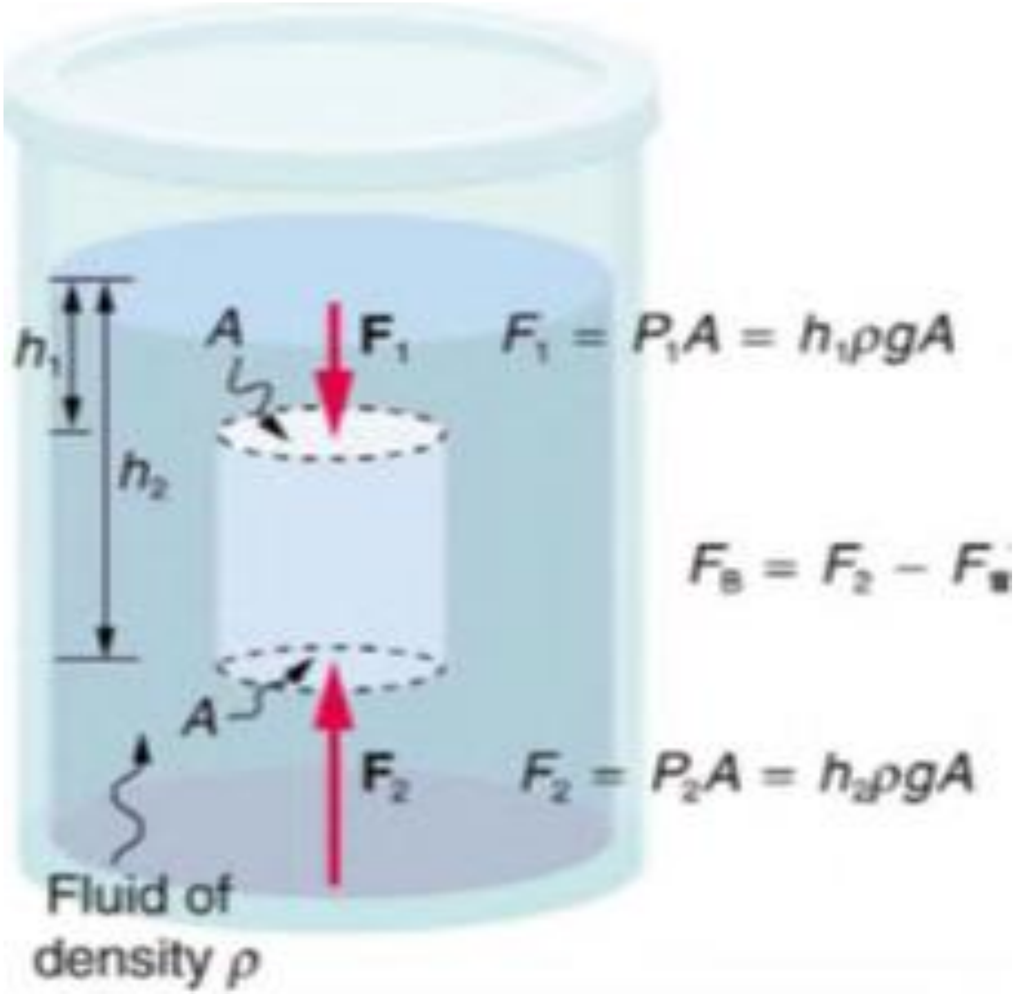


Figure : Pressure variation with depth resulting a buoyant force

A fully submerged object displaces a volume of fluid equal to its own volume.

$$V_{df} = V_o$$

- Buoyant force (F_B) is determined by the fluid's density and the object's volume.

$$F_B = \rho_f V_{df} g = \rho_f V_o g$$

- The object's weight depends on its density and volume.

$$F_g = mg = \rho_o g V_o$$

- The net force on floating & sinking object is:

$$F_{net} = F_B - F_g = (\rho_f V_{df} - \rho_o V_o) g$$

Submerged Objects:

- If $W_{object} < W_{df}$: object floats (Full floatation)
- If $W_{object} > W_{df}$: object sinks
- If $W_{object} = W_{df}$ (partially submerged)
  - ✓ object floats in equilibrium.
- If $W_{object} = W_{df}$ (Fully submerged)
  - ✓ object stays suspended (neither floats nor sinks).

Or

- If $\rho_{object} < \rho_{fluid}$: object floats (Full floatation)
- If $\rho_{object} > \rho_{fluid}$: object sinks
- If $\rho_{object} = \rho_{fluid}$: object stays suspended (neither floats nor sinks).

Floating Objects:

- The volume of the object submerged is proportional to the ratio of the object's density to the fluid's density.

Partially submerged object

- ✓ object float in state of equilibrium if the buoyant force equals the weight of the object.

$$\rho_f V_{df} g = \rho_o g V_o \Rightarrow \frac{V_{df}}{V_o} = \frac{\rho_o}{\rho_f}$$

Fully submerged object

- object neither float nor sink (remain suspended) if the buoyant force equals the weight of the object.

$$\frac{V_{df}}{V_o} = \frac{\rho_o}{\rho_f} = 1$$

- ✓ *density of the object is equal to density of the fluid*

Note

For object float in state of equilibrium (partially submerged) & stays suspended (fully submerged in fluids), the net force is zero.

$$F_{net} = F_B - F_g = (\rho_f V_{df} - \rho_o V_o)g = 0$$

Factors Affecting Submersion:

- ✓ Density of the object compared to the fluid.
- ✓ Larger buoyant forces on objects with lower density than the fluid, making them harder to submerge.

Examples

1. An iceberg floats in seawater as shown in Fig. below. What fraction of the iceberg lies below the water level? Density of sea water and icebergs are 1030 and 917 kg/m^3 respectively.

2. (a) Calculate the buoyant force on 10,000 metric tons (1.00×10^7 kg) of solid steel completely submerged in water, and compare this with the steel's weight.

(b) What is the maximum buoyant force that water could exert on this same steel if it were shaped into a boat that could displace $1.00 \times 10^5\ m^3$ of water?

3. The mass of an ancient Greek coin is determined in air to be 8.630 g. When the coin is submerged in water, its apparent mass is 7.800 g. Calculate its density, given that water has a density of $1.0\ \text{g/cm}^3$ and that effects caused by the wire suspending the coin are negligible.

Activity!

A block of wood has density of 600 kg/m^3 & a volume of 0.1 m^3. Calculate:

a) The volume of water displaced when the block is floating.

b) The percentage of the block volume that remains above the water surface.

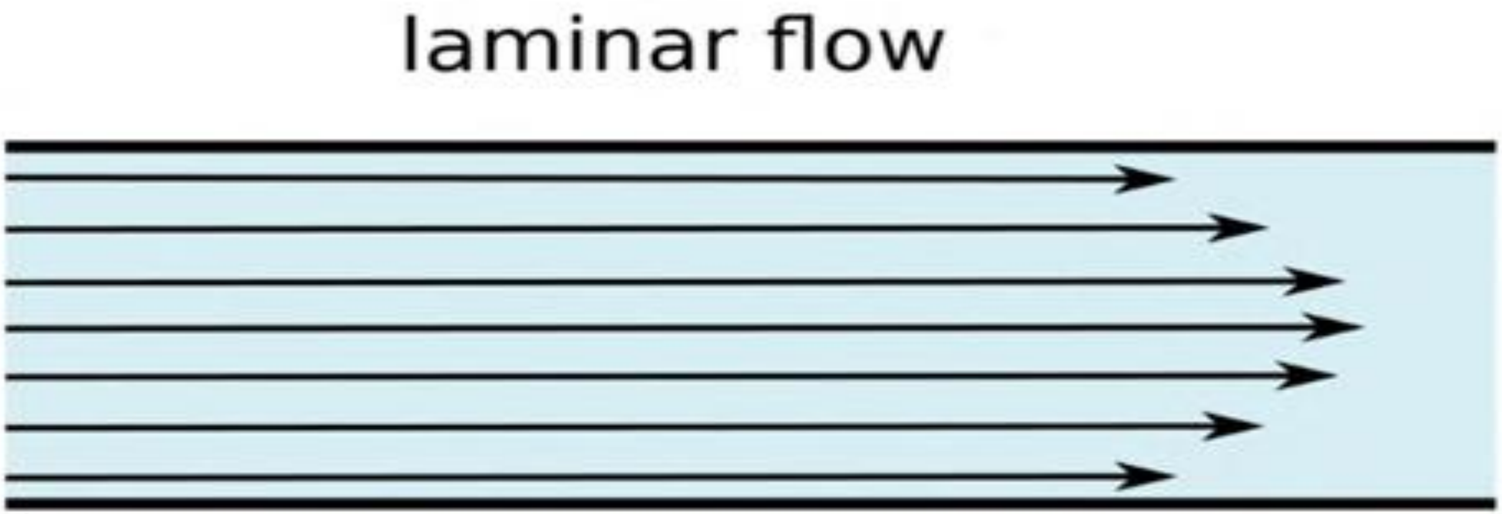
3.4 Fluid Flow

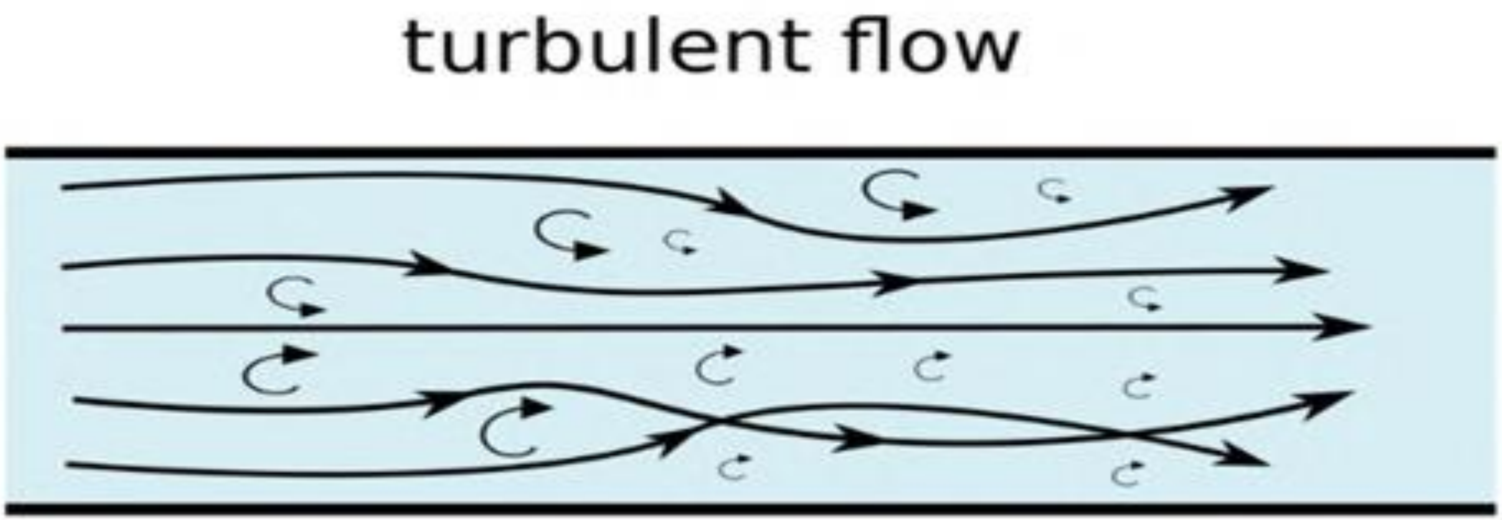
- is caused by differences in pressure.
  - ✓ When the pressure in one region of the fluid is lower than in another region, the fluid tends to flow from the higher pressure region toward the lower pressure region.

    For example, large masses of air in Earth's atmosphere move from regions of high pressure into regions of low pressure creating what we call wind.

Types of Fluid Flow:

1. Laminar Flow: smooth, regular flow with parallel streamlines, occurs at low velocities and small pipes.
2. Turbulent Flow: chaotic, irregular flow with whirlpools occurs at high velocities and in large pipes.
   - ✓ *Every adjacent layer cross each other and move in zigzag manner.*


laminar flow


turbulent flow

Steady vs. Unsteady flow

Steady flow: the flow rate remains constant over time.

Unsteady flow: the flow rate changes over time.

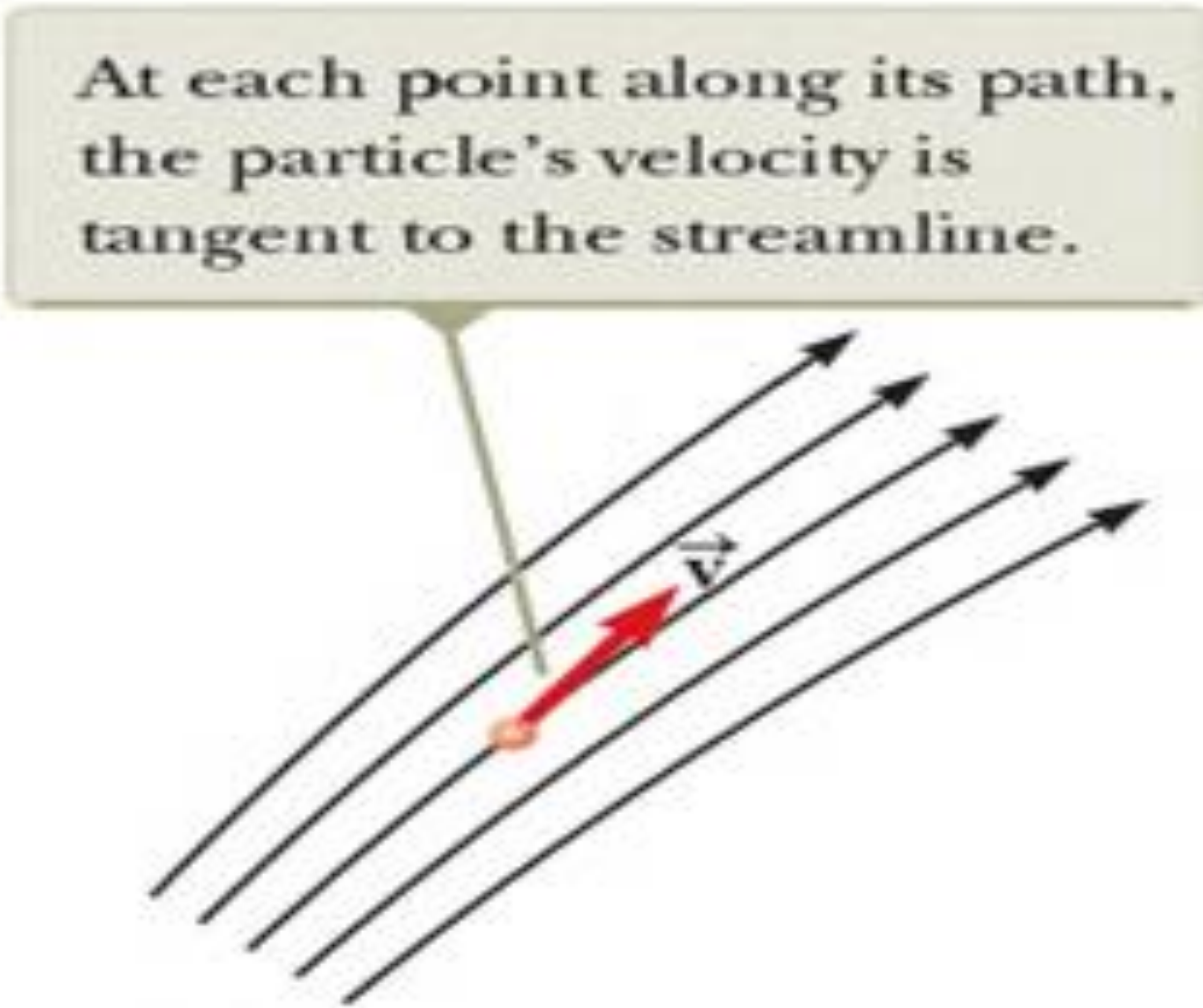
Viscosity:

- ✓ Internal friction in fluids that causes a transformation of kinetic energy into internal energy.

Streamlines:

- ✓ represent the path of fluid particles in steady flow; velocity is tangent to streamlines.
- ✓ concerned with the path of particles of fluids.
- ✓ affected by:
  - Velocity of the fluid
  - Fluid density
  - Viscosity of the fluid

- Shape of the object
- etc.



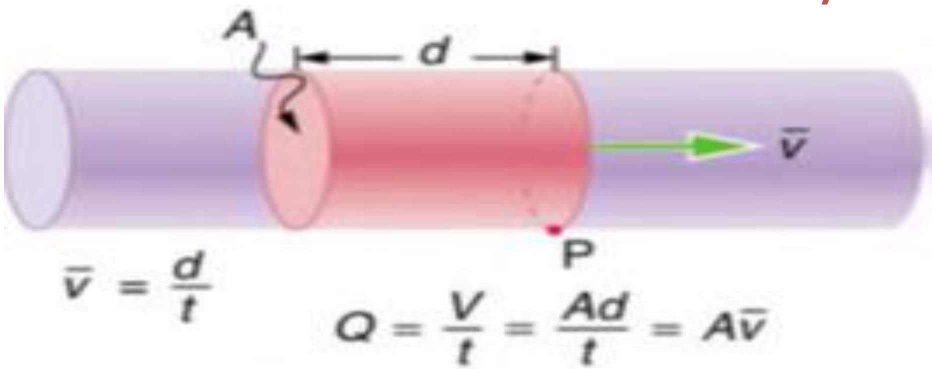
Flow Rate (Q):

- ✓ quantifies the movement of fluids through the a system.
- ✓ volume of fluid passing a point per unit time:

$$Q = \frac{V}{t}$$

where; V is the volume and t is the elapsed time.

- ✓ the SI unit for flow rate is m^3/s.



Factors affecting flow rate

1. Cross-sectional area

- ✓ A larger area allows more fluid to pass through, increasing the flow rate.

2. Velocity:

- ✓ Higher fluid velocity leads to a higher flow rate.

3. Viscosity of the fluid

- ✓ High viscosity (thickness) reduces the flow rate due to increased resistance.

4. Pressure difference

- ✓ **Higher pressure differences between two points in all fluid system can increase the flow rate.**

5. Pipe roughness

- ✓ A rougher surface inside the pipe increases friction, reducing flow rate.

Example

How many cubic meters of blood does the heart pump in a 75-year lifetime, assuming the average flow rate is 5 L/min?

Equation of Continuity (conservation of mass):

- ✓ relate the cross-sectional area and average speed of fluid flow in different parts of a rigid vessel carrying an incompressible fluid.
- ✓ For incompressible fluids, flow rate is constant:

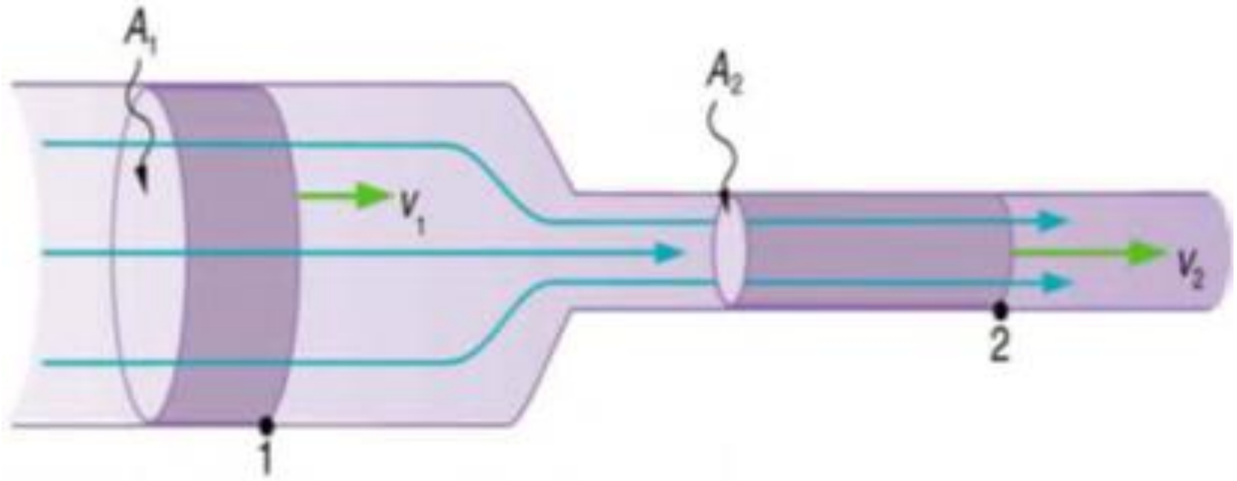
$$Q_1 = Q_2$$

$$v_1 A_1 = v_2 A_2$$

Where A is the cross-sectional area and v is the fluid velocity.

Note that!

Because the cross-sectional area of the pipe decreases, the velocity must necessarily increase ⇒ flow rate must be the same at all points along the pipe. In particular, for points 1 and 2.



- The equation of continuity is valid for all liquids (incompressible) and must be applied with caution to gases if they are subjected to compression or expansion.

Example

A nozzle with a radius of 0.250 cm is attached to a garden hose with a radius of 0.900 cm. The flow rate through hose and nozzle is 0.500 L/s. Calculate the speed of the water

(a) in the hose and

(b) in the nozzle.

- As fluid speed increases, the pressure it exerts on a surface decreases (Bernoulli's principle).

Pressure Energy/ Static pressure

Kinetic Energy / Dynamic pressure

Gravitational Potential Energy per volume

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

- ✓ In horizontal flow, where height does not change, the equation is simplified to;

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

- ✓ If velocity increases, pressure decreases to be the sum remain constant or vice versa. e.g. : in airplane wing.

Applications of fluid flow:

- Biological Systems: Blood flow and snoring are influenced by fluid speed and pressure.
- High-Pressure Equipment: Used in cooking, gas storage, inflators, washers, and scientific studies.

High-Pressure Safety:

- Causes of failure: damaged equipment, poor maintenance, incorrect installation, and operator error.
- Safety measures: use proper design, maintenance, training, and correct installation.

High-Pressure Components:

1. Compressors: Increase gas pressure by reducing volume.
2. Piping: Transports fluids; must handle high pressures and temperatures.
3. Vessels: Contain fluids under pressure.
4. Safety Accessories: Include safety valves, bursting discs, and limiting devices.

High-Pressure Effects:

- ✓ Can transform physical and chemical properties of materials.
- ✓ Used in biological, material science, food technology, and environmental engineering fields.

High-Pressure Gas Cylinder:

- A container that stores gas under high pressure.
- Commonly used for LPG storage.
- Made of metal to handle pressurized gas safely.
- Releases gas in a controlled manner for fuel or industrial use.

Key Safety Consideration:

- Strict safety precautions are necessary to avoid accidents.

LPG Gas Cylinder Safety Measures:

Safety Guidelines:

- ✓ *Keep the cylinder upright on a flat, ventilated surface.*
- ✓ *Store in a location protected from physical damage.*
- ✓ *Keep inflammable materials (e.g., kerosene) away.*
- ✓ *Turn off the cylinder knob after use to prevent leaks.*
- ✓ *Keep the knob out of children's reach.*
- ✓ *Educate others on gas safety and proper handling.*
- ✓ *Avoid prolonged use while cooking.*

High-Pressure Washer:

- A cleaning device that uses a high-pressure water jet.
- Powered by electricity or gas.
- Used for cleaning outdoor surfaces, vehicles, machinery, etc.
- Removes dirt, grease, grime, rust, and paint efficiently.

Key Feature:

- Equipped with a narrow nozzle to focus water pressure.

High-Pressure Washer Safety Measures

Safety Guidelines:

- ✓ *Wear safety glasses to prevent eye injuries.*
- ✓ *Use enclosed shoes (work boots) for foot protection.*
- ✓ *Wear gloves to protect hands from injury.*
- ✓ *Use ear protection for extended gas-powered washer use.*
- ✓ *Never aim the washer at people or pets.*
- ✓ *Maintain proper standing posture while using the washer.*
- ✓ *Turn off the machine and water before disconnecting hoses.*

Figure : Application of high pressure washer

The end!
Thank you!