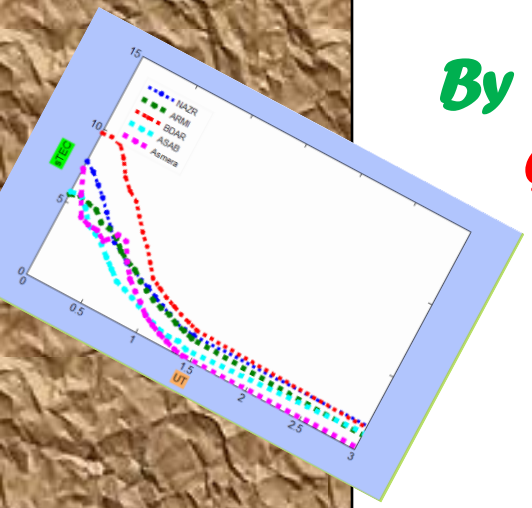


UNIT-THREE

FLUID MECHANICS.



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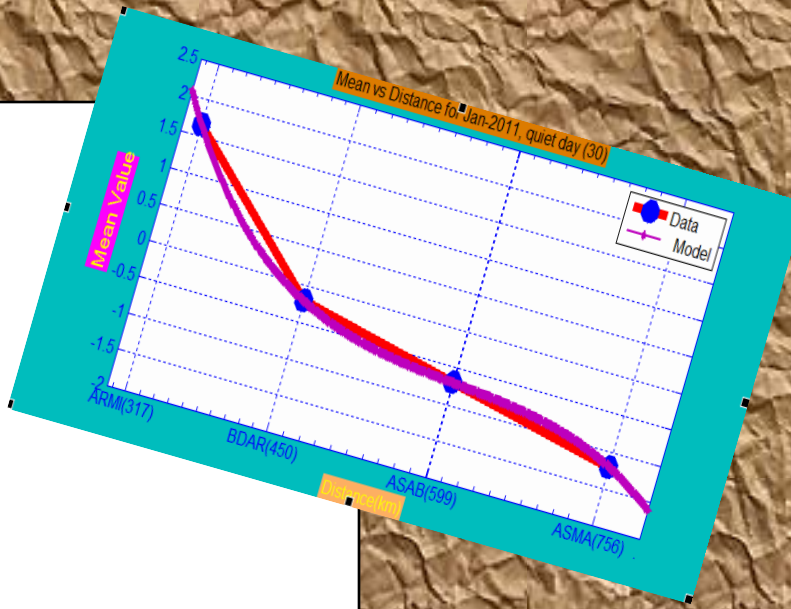


Outline of the talk

FLUID MECHANICS

- Pressure in fluids at rest
- Archimedes' principle
- Fluid flow
- Safety and high pressure

Introduction

- Matter most commonly exists as solids, liquids or gases.
- Liquid and gas are both fluids: in contrast to solids they lack the ability to resist deformation. As a result fluid moves, or flows under the action of the force.
- Fluid mechanics refers to the study of fluid behaviour at rest and in motion.
- Fluid mechanics has a wide range of applications in mechanical and aerodynamic engineering, in biological systems, and in many more fields.

3.1 Fluid Statics

- Why are gases easy to compress, while liquids and solids are almost incompressible?

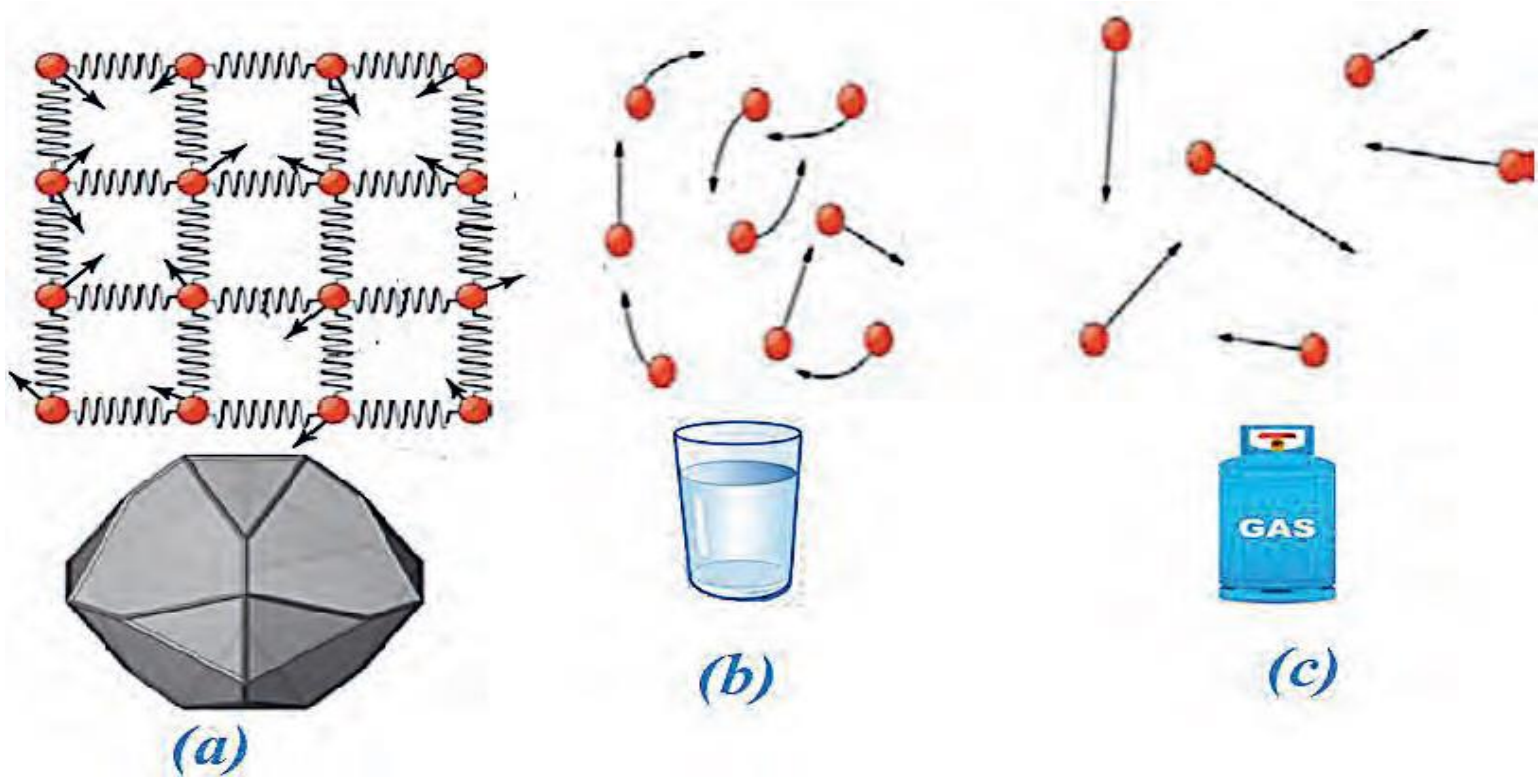
- **Fluid statics** or **hydrostatics** is the branch of fluid mechanics that studies fluids at hydrostatic equilibrium.
- It encompasses the study of the conditions under which fluids are at rest in stable equilibrium as opposed to fluid dynamics, the study of fluids in motion. Hydrostatics is a subcategory of fluid statics, which is the study of all fluids, both compressible or incompressible, at rest.

Con…

- Fluid statics is used to determine the forces acting on floating or submerged bodies and the forces developed by devices like hydraulic presses and car jacks.
- The design of many engineering systems such as water dams and liquid storage tanks requires the determination of the forces acting on their surfaces using fluid statics.

Properties of solids, liquids and gases

- Atoms in solids are very close to each other. The forces between them acts as a spring that allow the atoms to vibrate without changing positions relative to their neighboring atoms (Fig).



Con…

- Solids also resist compression, because their atoms are relatively fixed distance apart. Under compression, the atoms would be forced into one another. Solid resist all types of stress because the atoms are not able to move about freely.
- In a liquid, the intermolecular forces are weaker relative to solids, but still strong compared with gases. Liquids deform easily when stressed and do not spring back to their original shape once the force is removed because the atoms are free to slide about and change neighbors.

Con…

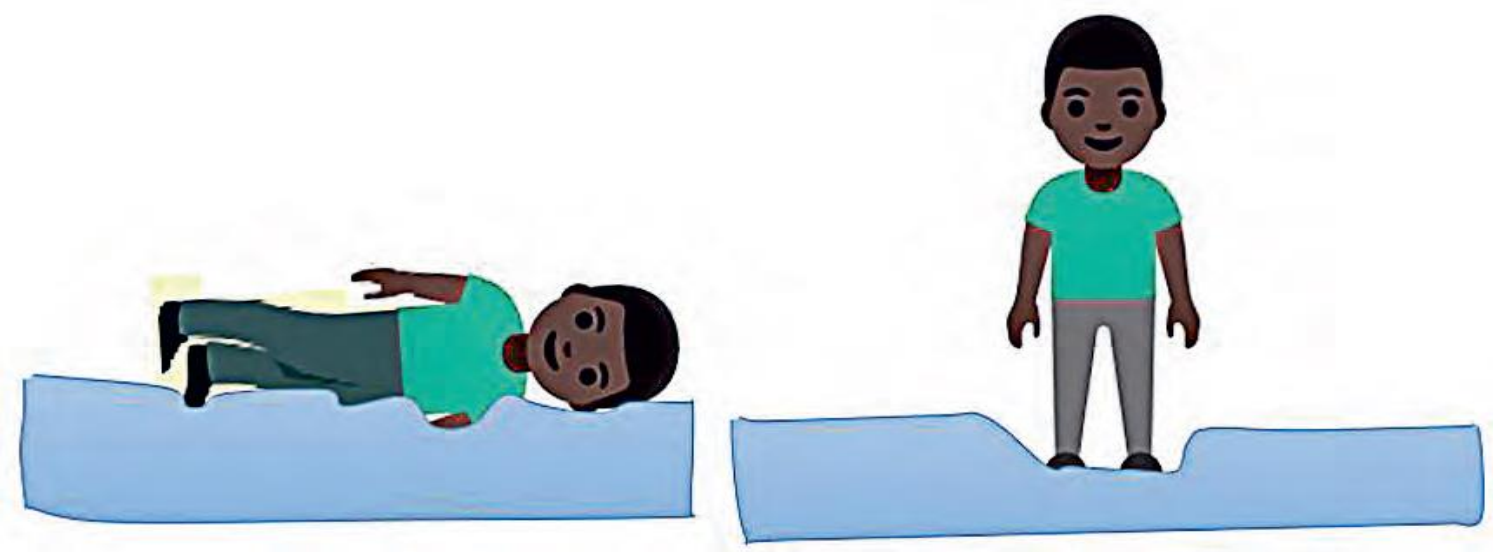
- Atoms in gases are separated by distances that are large compared with the size of the atoms. The forces between gas atoms are therefore very weak, except when the atoms collide with one another.

➢The properties of solids, liquids and gases can be observed from the following simulation link:

➢https://phet.colorado.edu/sims/html/states-of-matter-basics/latest/states-of-matter-basics_en.html.

Pressure in Fluid

- ✓ The normal component of a force acting on a surface per unit area is called the normal stress, and 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.



Con…

- ✓Pressure is a normal force exerted by a fluid (or a solid) per unit area.

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

- ✓The unit of pressure is pascal (Pa).
- ✓ 1Pa = 1 N/m2

- ✓1 *atm* = 760*mmHg* = 760 *torr* = 101.3 *KPa* = 14.7 *psi*

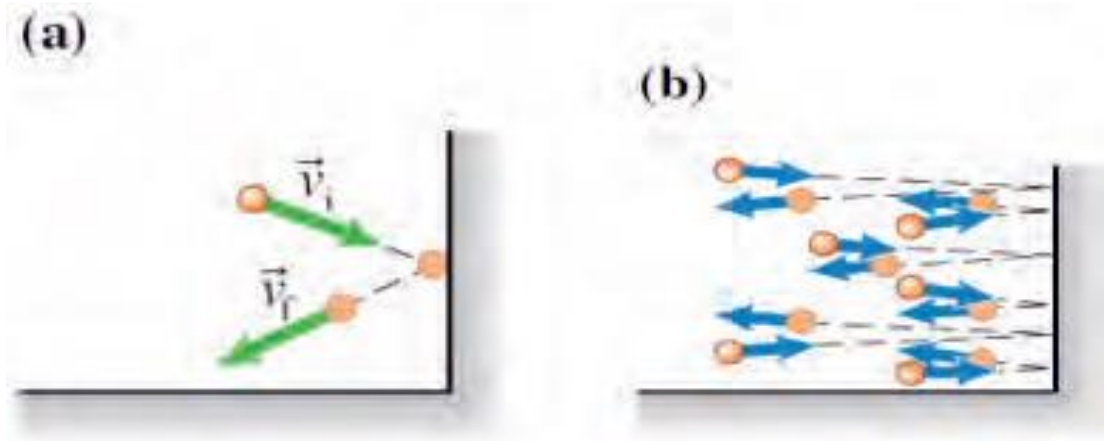
Examples

1. As a woman walks, her entire weight is momentarily placed on one of her shoes. Calculate the pressure exerted on the floor by the shoe if it has an average width 10 cm and average length of 30 cm and the woman's mass is 55.0 kg.
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 1.00mmdiameter to create a pressure of 3.00£109 $N/m2$.

Pressure in Gases

- As air particles move randomly in space, they eventually collide with the solid surfaces of any objects in that space. In each of these collisions, the particle exerts an impulsive force on the object.
- when a huge number of particles bombard a solid surface at a constant rate, these collisions collectively exert an approximately constant force on the object.
- Absolute and gauge pressures are related to each other by:

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



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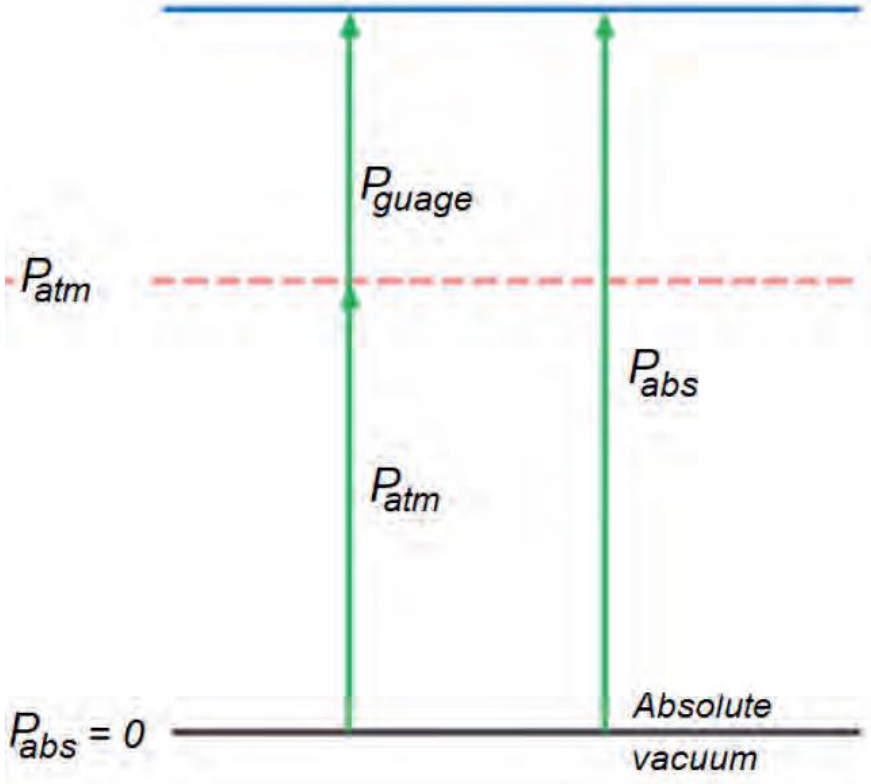
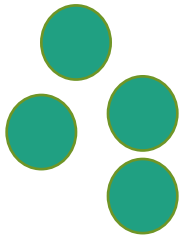
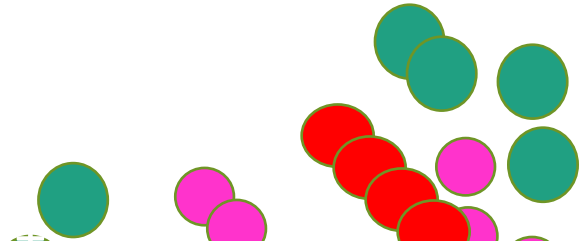


- Like other pressure gauges, the gauge used to measure the air pressure in an automobile tire reads the gauge pressure.







Example

1. The absolute pressure in water at a depth of 8 m is read to be 175 kPa. Determine the local atmospheric pressure if the guage pressure at this depth is 78.4 Kpa.

Solution:

The absolute pressure in a water at a depth of 8 m is given as 175 KPa

$$P_{loc.atm} = P_{abs} - P_{gauge}$$

$$= 175\ Kpa - 78.4\ KPa = 96.6\ KPa$$

We can observe that the local atmospheric pressure is less than the atmospherics pressure at sea level.

Density

- The density of most gases is proportional to pressure and inversely proportional to temperature.
- Liquids and solids, on the other hand, are essentially incompressible substances, and the variation of their density with pressure is usually negligible.

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

Relative density

❖ Specific gravity, or relative density is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4 C^0, for which $pH2O$ = 1000 kg /m3).

That is;

$$\text{specific gravity} = S_G = \frac{\rho}{\rho_{H_2O}}$$

➢Note that the specific gravity of a substance does have any unit.

➢Note that substances with specific gravities less than 1 are lighter than water, and thus they would float on water.

Ideal Gas Equation

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

$$PV = nRT = \frac{m}{M}RT = mR_{specific}T$$

$$P = \frac{m}{V}R_{specific}T = \rho R_{specific}T$$

- $R_{specific} = R/M$ ($R/M = 0.287$ kPa.m3/kg.K) is the specific gas constant. The specific gas constant is different for different gases and R is the universal gas constant whose value is R = 8.314 J/mol. K and M is the molar mass of the gases.

Example

1. Determine the density, specific gravity, and mass of the air in a room whose dimensions are 4m, 5m and 6m at 100 kPa and 25 C^0 (Figure 3.10).

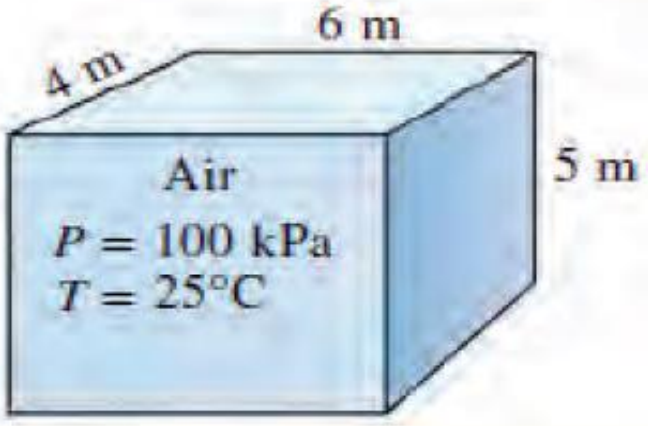


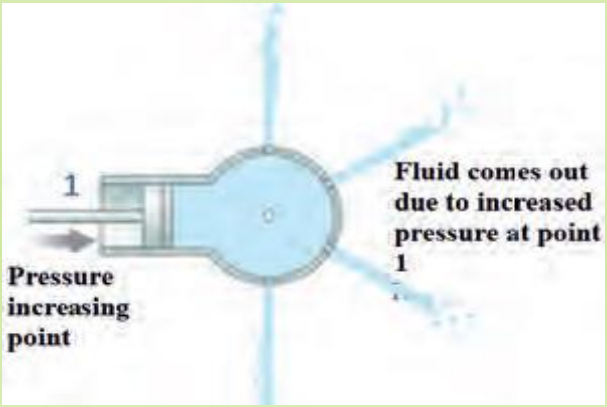
Figure 3.10 Dimension of air at 25℃ and 100 kPa

Pressure in Fluids at Rest

- The particles in a liquid are in continual random motion, somewhat similar to particles in gases.

Pascal's principle

- **Pascal's principle**: States that a change in the pressure applied to a static fluid is transmitted undiminished to every point of the fluid and to the walls of the container.



Hydraulic Press

- Automobile mechanics use hydraulic presses to lift cars, and dentists and barbers use them to raise and lower their clients' chairs. The hydraulic brakes of an automobile are also a form of hydraulic press.
- A **hydraulic press** is a machine press using a hydraulic cylinder to generate a compressive force.
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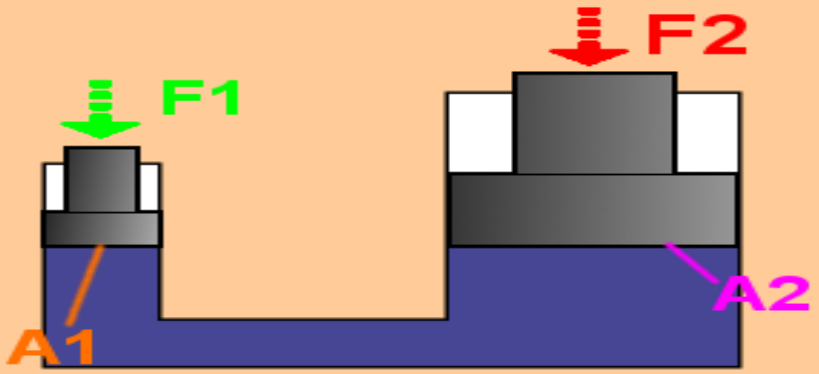
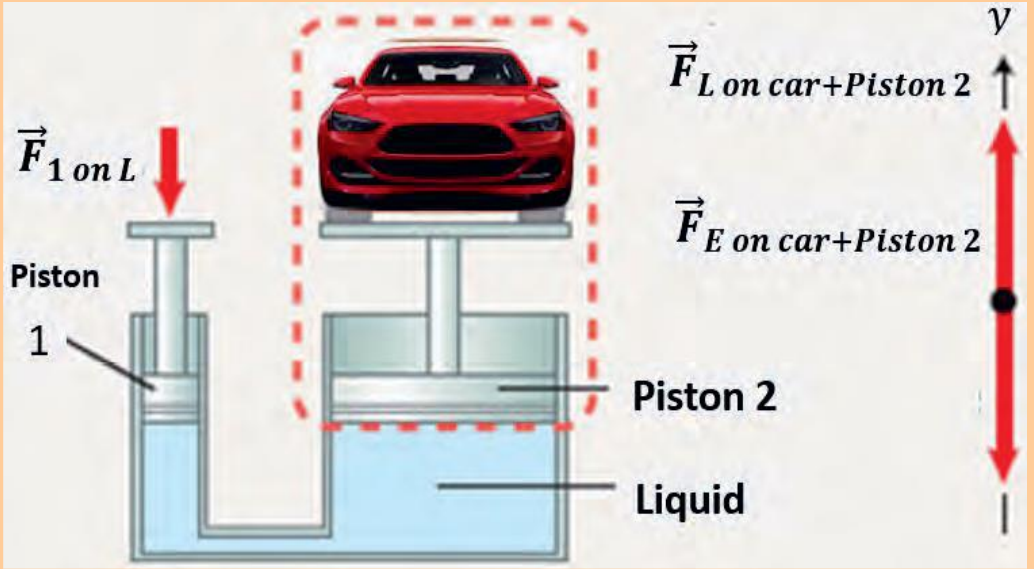
$$\frac{F1}{A1} = \frac{F2}{A2}$$

F2=F1 (A2/A1)





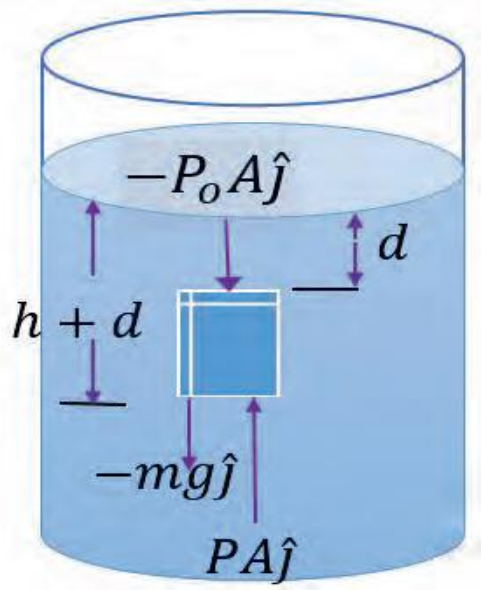
Example

1. A hydraulic lift has a small piston with surface area 0.0020m2 and a larger piston with surface area 0.20m2. 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

- The pressure due depth of liquid is independent of the shape and size of the container, it only depends on the depth.
- The equation ***P* = ρgh** represents the pressure due to the weight of any fluid of average density **ρ** at any depth h below its surface. For liquids, which are nearly incompressible, this equation holds to great depths.

$$P = P_o + \rho h g$$



Con…

P_o is the pressure at the surface of the liquid, then P_o is atmospheric pressure.

$$P_o = 1.00\ atm = 1.013\,3 \times 10^5\ Pa$$

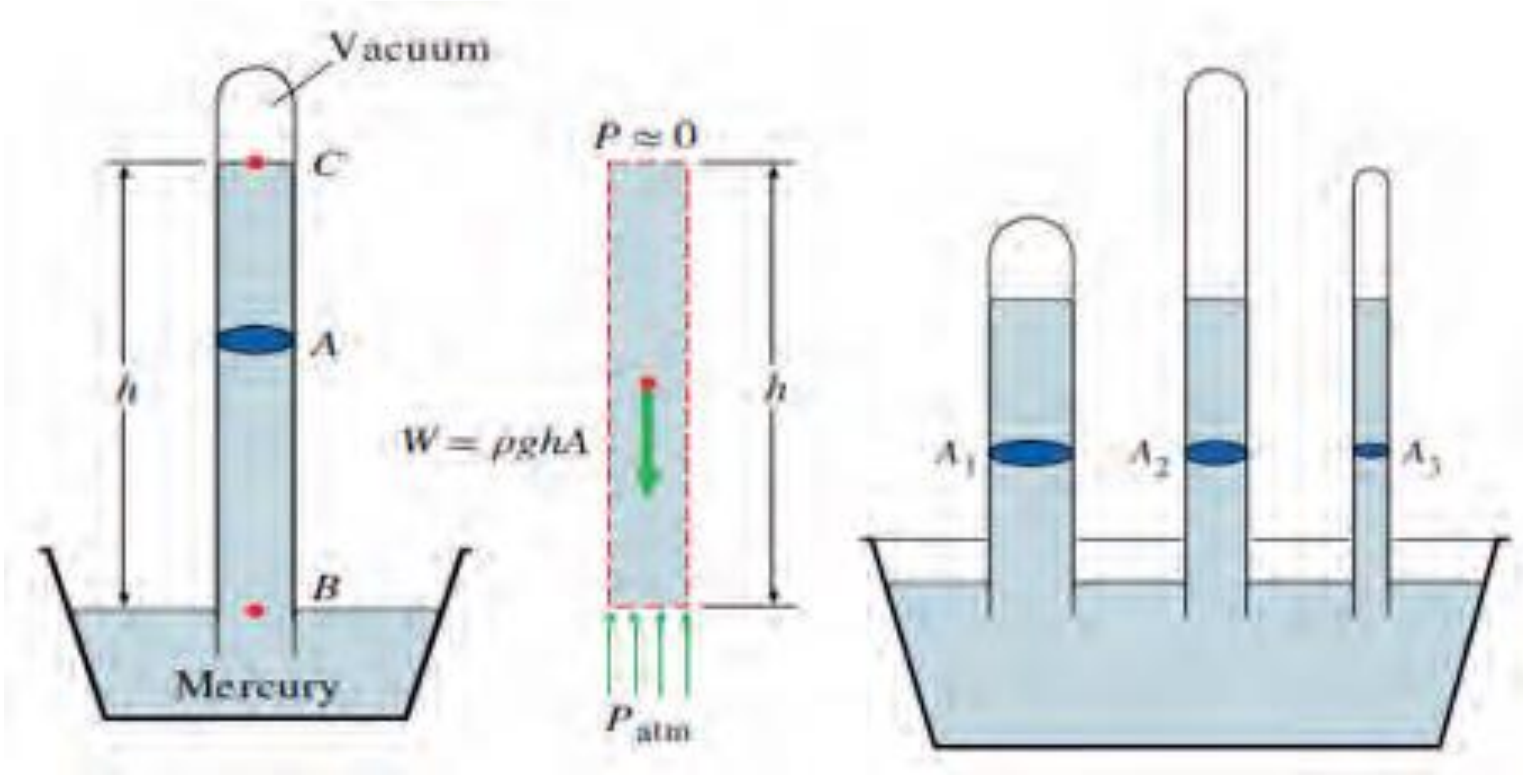
Example

1. Calculate the force on a circular area of diameter 0.40 m on the bottom of the ocean which is 25.0mbelow the surface. Take atmospheric pressure and density of sea water at the bottom to be 1 atm and 1.03 K *kg* /*m*3 respectively.

Measuring pressure

Barometer : Atmospheric pressure is measured by a device called a *barometer*; thus, the atmospheric pressure is often referred to as the barometric pressure.

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



Example

1. 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^0, at which its density is 13,595 *kg* /*m*3).

The Manometer

❖ A manometer is a device similar to a barometer that can be used to measure the pressure of a gas trapped in a container. A closed-end manometer is a U-shaped tube with one closed arm and the other arm connected to the gas whose pressure is to be measured, and a non volatile liquid (usually mercury) in between.

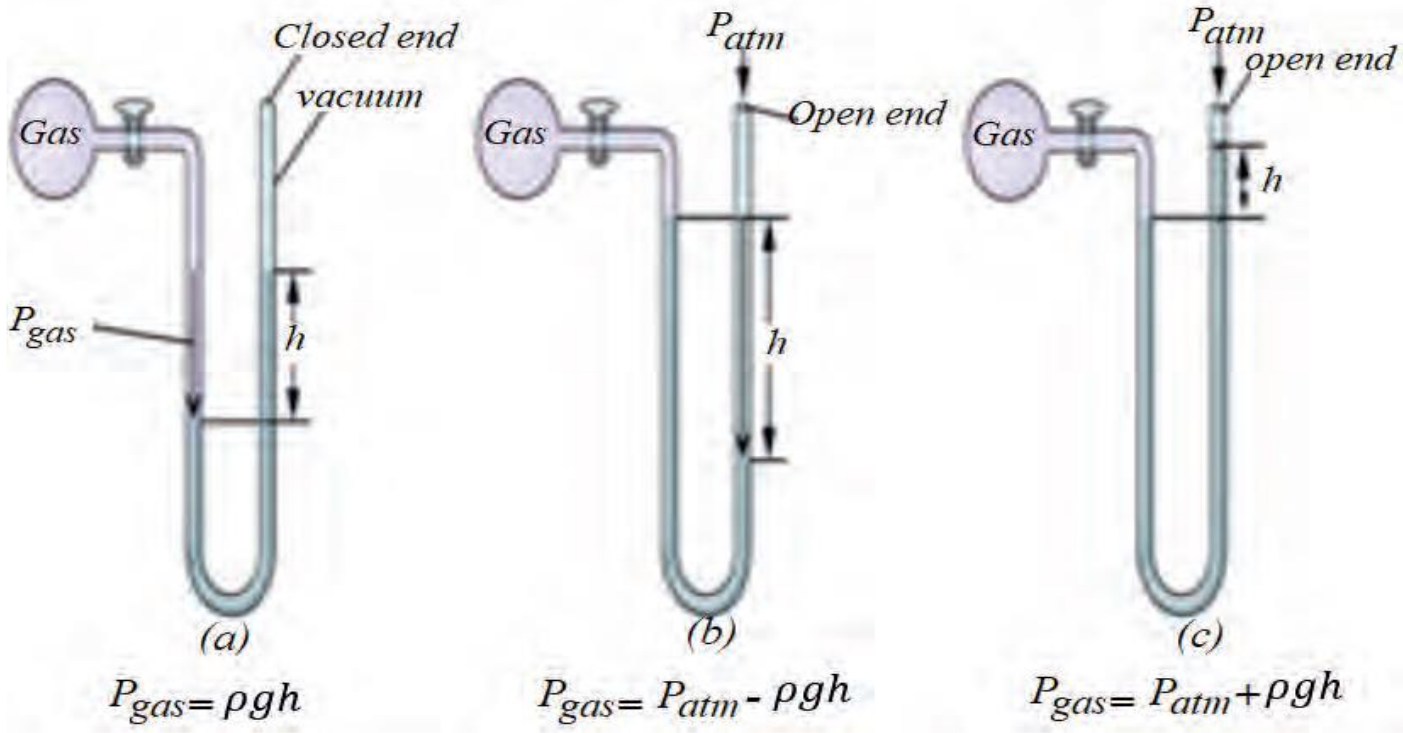


Figure 3.18 Measurement of gas pressure with manometer (a) closed end manometer (b) open end manometer with atmospheric pressure greater than gas pressure (c) open end manometer with atmospheric pressure less than gas pressure

Con…

- This device is mainly used to measure low pressure differences accurately. The pressure in the gas supply (P_{gas}) for the situations are given as follow:

(a) For closed end manometer:

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

(b) For open end manometer with atmospheric pressure greater than gas pressure:

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

(c) open end manometer with atmospheric pressure less than gas pressure:

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

Con..

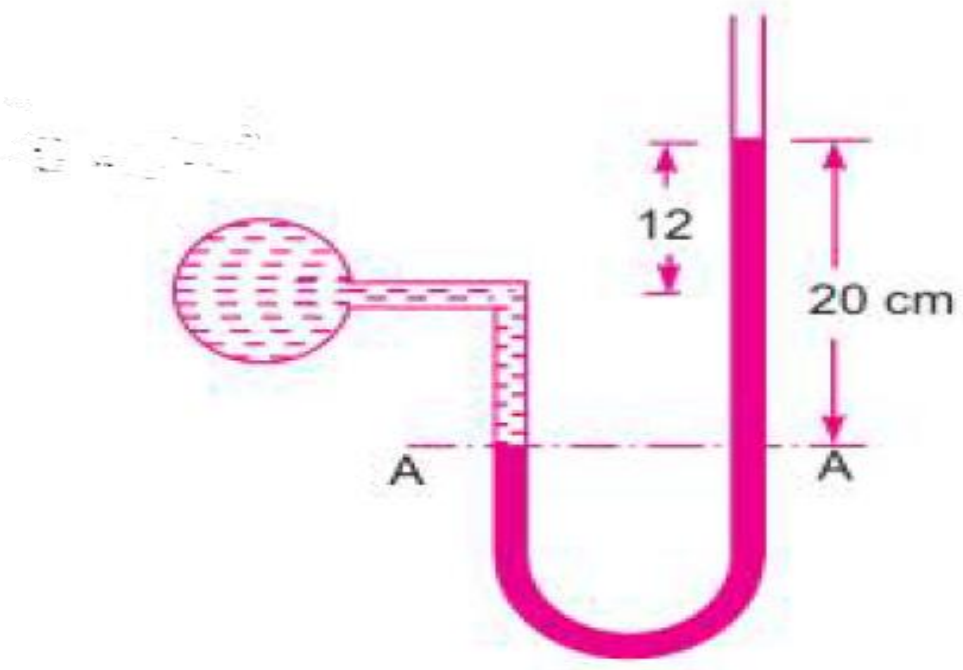
✓Where ρ denotes density of the liquid, g denotes gravitational constant, h is the height of the liquid column.

Example

1. 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 armis 55 cm above the gas connected arm, as shown in Figure 3.18. If the local atmospheric pressure is 96 kPa, determine the absolute pressure within the tank.

Con...

2. The right limb of a simple U-tube manometer containing mercury is open to the atmosphere while the left limb is connected to a pipe in which a fluid of SG 0.9 is flowing. The center of the pipe is 12cm below the level of mercury in the right limb (SG of Hg 13.6). Find the pressure of the fluid in the pipe if the difference of mercury level in the two limb is 20cm.



Archimedes' principle

❖ Archimedes' principle is Stated as : the buoyant force on an object equals the weight of the fluid it displaces. In equation form, Archimedes' principle is given as:

✓ $F_B = W_{fluid}$ $$F_B = \rho_{fluid} g V_{disp}$$

Buoyant force: It is extremely difficult to push a ball down under water because of the large upward force exerted by the water on the ball. The upward force exerted by a fluid on any immersed object is called a **buoyant force**. Buoyant force is based on the fact that pressure increases with depth in a fluid. This means that the upward force on the bottom of an object in a fluid is greater than the downward force on the top of the object. This Buoyant force is also called up thrust force.

Totally submerged object

- When an object is totally submerged in a fluid of density ρ_{fluid} , the volume V_{disp} of the displaced fluid is equal to the volume of the object V_{obj} ; so, the magnitude of the upward buoyant force is $F_B = \rho_{fluid}.g.V_{obj}$
- If the density of the object is greater than the density of the fluid, the upward buoyant force is less than the downward gravitational force and the unsupported object sinks.
- If the density of the submerged object equals the density of the fluid, the net force on the object is zero and the object remains in equilibrium.

Floating Object

- Consider an object of volume V_{obj} and density $\rho_{obj} < \rho_{fluid}$ in static equilibrium floating on the surface of a fluid, that is, an object that is only partially submerged.

$$\frac{V_{disp}}{V_{obj}} = \frac{\rho_{obj}}{\rho_{fluid}}$$



Example

1. An iceberg floats in seawater as shown in Figure. What fraction of the iceberg lies below the water level?

(Density of sea water and icebergs are 1030 *kg* /*m*3 and 917 *kg* /*m*3 respectively).



Con…

2. Compute the buoyant force on 10,000 metric tons (1 x 10^7 kg) of solid carbon steel completely submerged in water, and compare this with the steel's weight. ($\rho_{steel} = 7.84\ x\ 10^3\ kg\ /m3$)

3. What is the maximum buoyant force that water could exert on this same steel if it were shaped into a boat that could displace

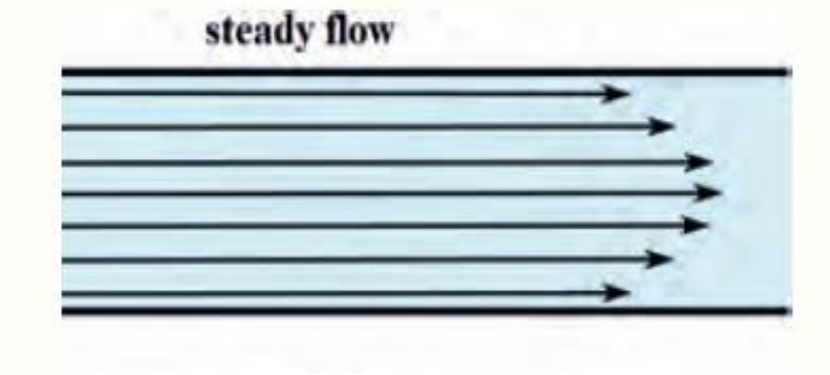
$1 \times 10^5\ m^3$ of water?

Fluid Flow

- In physics, a **fluid** is a liquid, gas, or other material that may continuously move and deform (***flow***) under an applied shear stress, or external force.
- 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.`

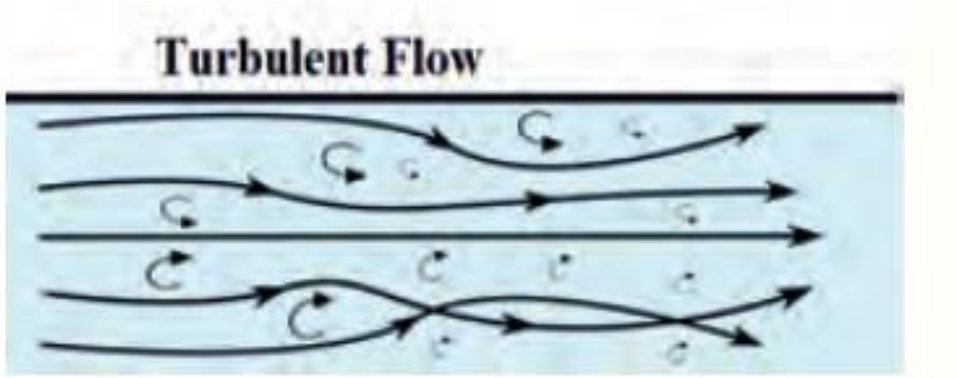
Steady and turbulant fluid flow

- In steady flow, every fluid particle arriving at a given point in space has the same velocity.



Con…

- Turbulent flow is irregular flow characterized by small whirlpool-like regions as shown in Fig.
- The adjacent layers of the fluid cross each other and move randomly in a zigzag manner. The turbulent flow occurs when the velocity of the fluid is high and it flows through larger diameter pipes.

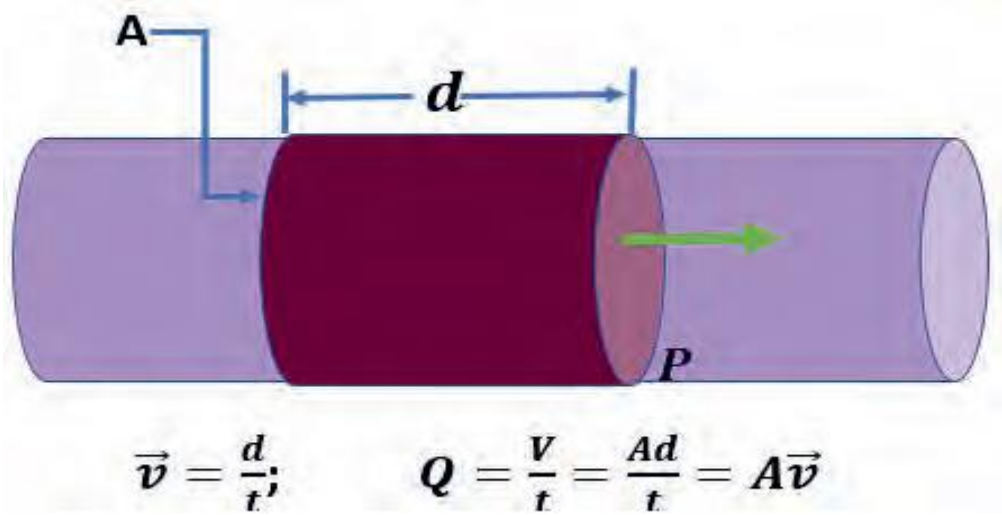


Flow Rate

❖Flow rate (Q) is defined to be the volume of fluid passing by some location through an area during a period of time.

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

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



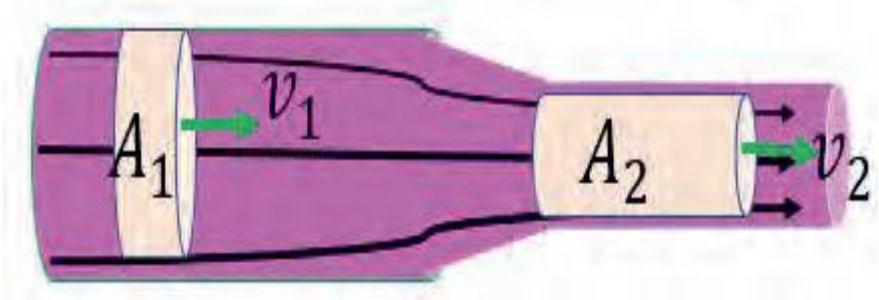
➢Example

1. 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

- Incompressible fluid flowing along a pipe . Because the fluid is incompressible, the same amount of fluid must flow past any point in the tube in a given time to ensure continuity of flow.
- The flow rate must be the same at all points along the pipe.

$$\left.\begin{aligned} Q_1 &= Q_2 \\ A_1 v_1 &= A_2 v_2 \end{aligned}\right\}$$



- The *equation of continuity* is used to relate the cross-sectional area and average speed of fluid flow in different parts of a rigid vessel carrying an incompressible fluid.
- *Equation of continuity* and is valid for any incompressible fluid where v_1 is the average speed of the fluid passing cross section A_1 and v_2 is the average speed of the fluid passing cross section A_2.

Example

1. 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

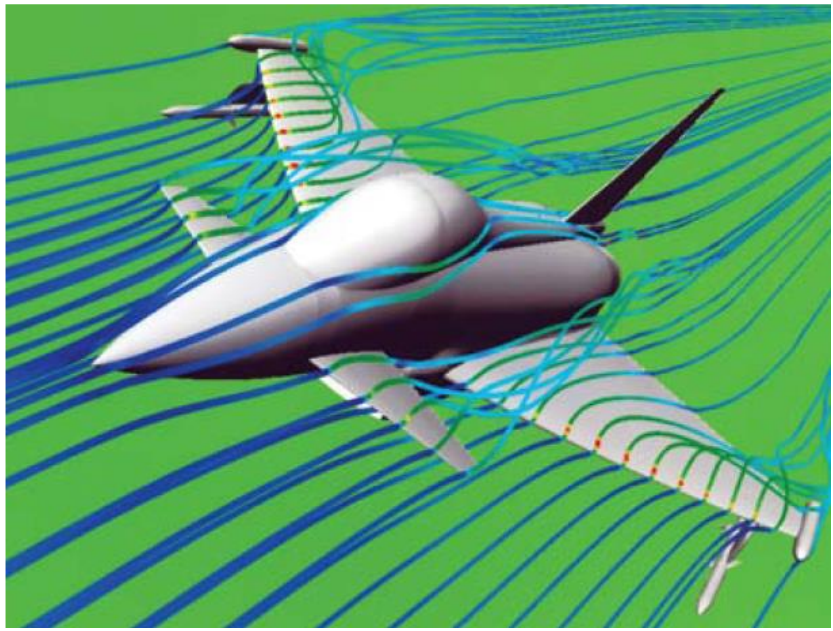
(a) in the hose and

(b) in the nozzle.

Bernoulli's Principle

- As a fluid's speed increases, the pressure that the moving fluid exerts on the surface decreases. This is called Bernoulli's principle.
- Bernoulli's principle stating that : as the *velocity of a fluid increases, the pressure exerted by that fluid decreases*.

$$\mathbf{P}_1 + \frac{1}{2}\rho\,\mathbf{v}_1^2 + \rho\mathbf{g}\,\mathbf{y}_1 = \mathbf{P}_2 + \frac{1}{2}\rho\,\mathbf{v}_2^2 + \rho\mathbf{g}\,\mathbf{y}_2$$



Example

1. Water flow through a pipe shown below. The water speed through the lower pop and a pressure gauge reads 75kpa. What is the reading of the pressure gauge on the upper pipe?

[r_1 = 1cm, r_2 = 2cm, v_1 = 5 m/s, y_1 = 0 cm, y_2 = 20cm]

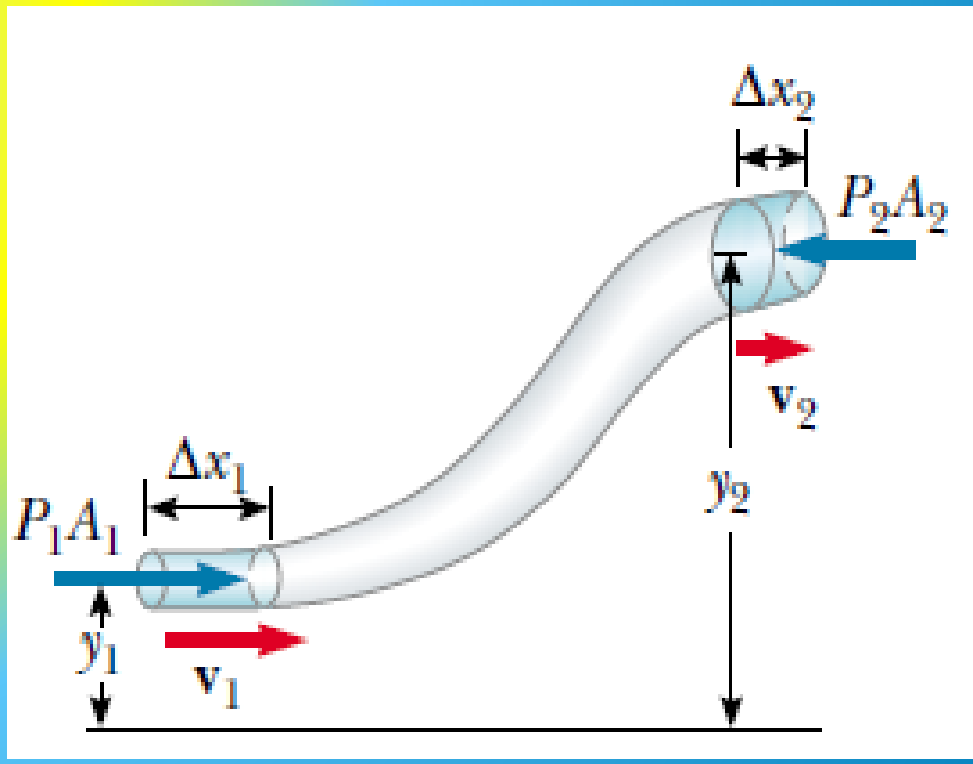
A. 75kpa

B. 84.25kpa

C. 24.6kpa

D. 4.6Kpa

E. None



Con...

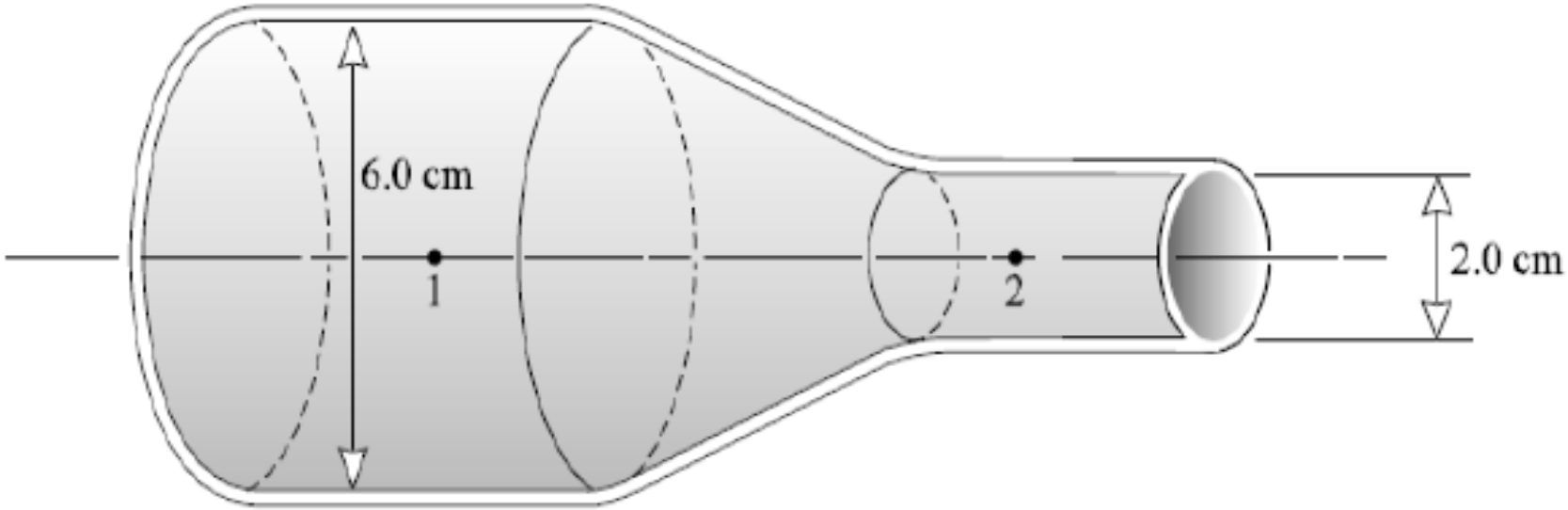
2. A horizontal pipe has a constriction in it, as shown in Fig. At point I the diameter is 6 cm, while at point "2" it is only 2 cm. At point "1", v_1 = 2 m/s and P_1 = 180 kPa. What are v_2 and P_2 at point 2?

A. 3 ms/s, 20kPa

B. 9 ms/s, 40kPa

C. 18 ms/s, 20kPa

D. 9 ms/s, 80kPa.



Safety and high pressure

❖ High Pressure Systems

- Pressure far greater than 1 atmosphere (most of the time greater than 50 atm) is considered as high pressure.
- High pressure is used for many applications. Such as:
- cookers are used in a kitchen to cook food.
- Gas cylinders containing liquid petroleum gas at high pressure are used as fuel.
- Gas cylinder are also used to seal different types of gases at high pressure for laboratory or medical use.
- The bicycle and car tires are inflated by high pressure tire inflator.
- High pressure is also used in high pressure washers.

Con…

- In physical science (physics and chemistry) high pressure is important to study physical properties of various materials (mainly solids) and to transform their nature.
- Many materials undergo fascinating changes in their physical and chemical characteristics when subjected to high pressure. The application of high pressure to biological samples is also of technological relevance because it is known that the microorganism activity is diminished or canceled by application of high pressures, a process called pascalization.
- Pascalization can be used to increase the shelf lives of perishable foodstuffs: juice, fish, meat, dairy products, etc.

Con…

- High pressure equipment may consist of:
- high-pressure compressors (or pumps),
- high pressure piping (fittings,
- seals, tubing and valves),
- high pressure vessels,
- Steam Generator,
- Safety Accessories and
- high-pressure instrumentation





Safety for high pressure equipment

- If pressure systems or equipment fails and bursts violently apart, it can seriously injure or kill people and cause serious damage to property.
- The main hazards from pressure are: impact from the blast of an explosion, impact from parts of equipment that fail or any flying debris, impact with the released liquid or gas (such as steam), fire resulting from the escape of flammable liquids or gases.

Con…

- Common causes of pressure system and equipment risks includes
  - Damaged equipment or system design
  - Poor or no maintenance
  - An unsafe system of work
  - Operator error due to lack of training/supervision
  - Incorrect installation
  - Inadequate repairs or modifications
- The safety measures to be taken to avoid the risks depends on the nature of the high pressure system.

Con…









Con…

- **Do the end of unit questions**

Con…..

