Chapter 1

Basic Concepts of Thermodynamic

History

- The term "thermodynamics" stems from Greek words:
  - thermo (heat)
  - dynamics (power)

  It was first used by Lord Kelvin in 1849.

- The term thermodynamic is most descriptive of early efforts to *convert heat into power.*

- Today, the same name is broadly interpreted as the *science of energy, that includes all aspects of energy* and energy transformation.

Dimensions and Units:

❑Any physical quantity can be characterized by dimensions. The arbitrary magnitudes assigned to the dimensions are called units. There are two types of dimensions, ***primary*** *or* ***fundamental*** *and* ***secondary*** *or* ***derived*** *dimensions.*

- Primary dimensions are: ***mass, m; length, L; time, t; temperature, T***
- Secondary dimensions are the ones that can be derived from primary dimensions such as: velocity (m/s^2), pressure (Pa = kg/m.s^2).

❑There are two unit systems currently available **SI** (International System) and USCS (United States Customary System) or English system.

❑The prefixes used to express the multiples of the various units are listed in Table 1-1.

Table 1: Standard prefixes in SI units.

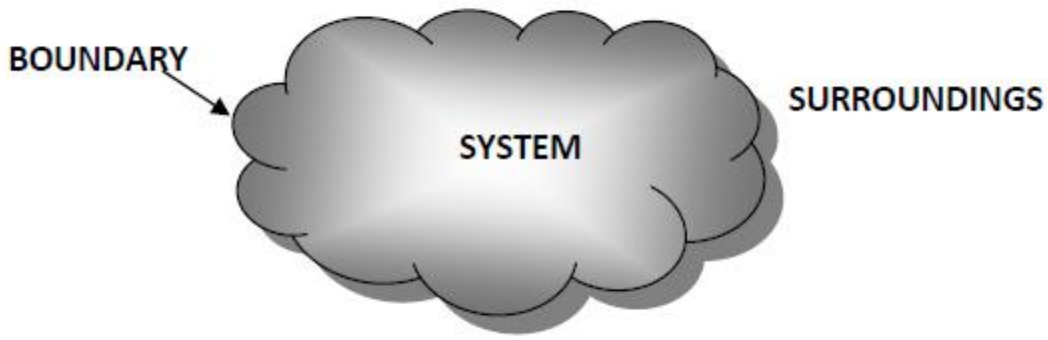
MULTIPLE	10^{12}	10^{9}	10^{6}	10^{3}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}
PREFIX	tetra, T	giga, G	mega, M	kilo, k	centi, c	mili, m	micro, µ	nano, n	pico, p

Thermodynamic Systems:-

- ***System:*** a quantity of matter or a region in space chosen for study.

- ***Boundary***: the real or imaginary surface that separates the system from its surroundings.

- ***Surroundings***: the region outside system.

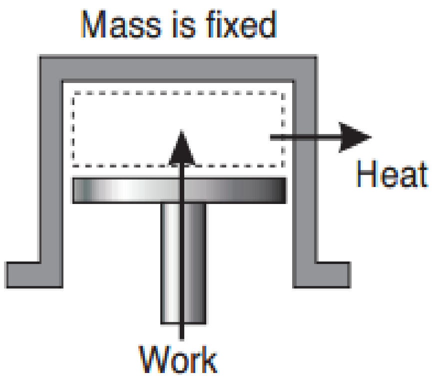


System, surroundings, and boundary

Thermodynamic systems are classified as either closed or open

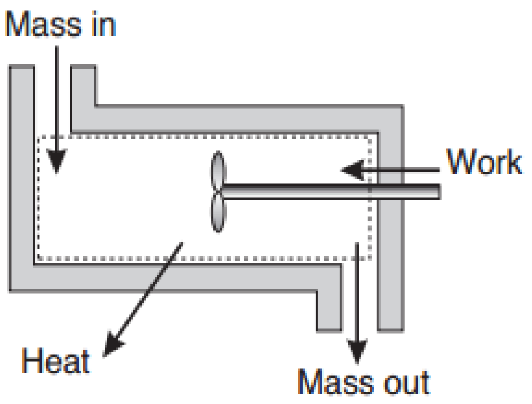
- **Closed System:**

– consists of a fixed mass
– NO mass crosses the boundary
– energy crosses the boundary as work and heat



- **Open System:**

– consists of a fixed volume
– mass crosses the boundary
– energy crosses the boundary as work and heat



Properties of a System:-

❑ **Properties:** *The characteristics of a system to which* numerical values can be assigned without knowledge of the history of the system, such as mass, volume, temperature, pressure, etc.

➢ ***Intensive properties:*** *are those that are independent* of the size of a system such as temperature (*T*), pressure (*P*), *and density. Shown by lowercase letters* (with *P and T being the obvious exceptions)*

➢ ***Extensive properties:*** *are those whose values* depend on the size of the system such as mass (*m*), volume (*V*), *and total energy (E). Shown by* uppercase letters with the exception of *m*.

➢ ***Specific properties:*** *are extensive properties per unit* mass and are shown by lowercase letters ($v = V/m$, $e = E/m$, $u = U/m$). *So they can be considered as*

State and Equilibrium

- ***The state***, *or the condition, of a system is described by a* set of properties.

Note:- At a given *state, all the properties of a system have fixed values. Thus, if the value of even*

- ***Equilibrium:***

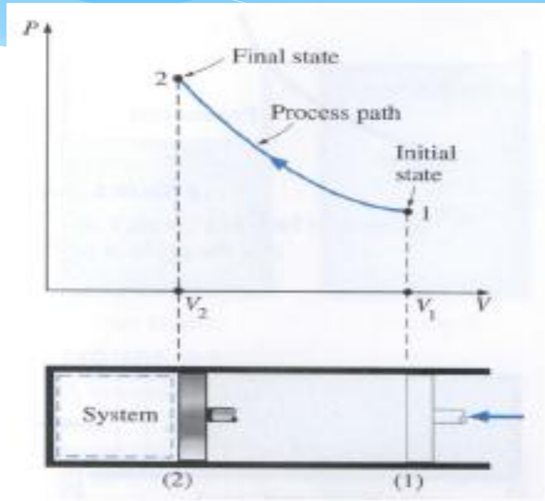
In an equilibrium state, there are no unbalanced potentials (or driving forces) within the system. A system in equilibrium experiences no changes when it is isolated from its surroundings.

The word equilibrium implies a state of balance:

- ***Thermal equilibrium:*** *The temperature is the* same throughout the system.
- ***Mechanical equilibrium****: No change in pressure* at any point of the system with time.
- ***Phase equilibrium:*** *Mass of each phase reaches* an equilibrium level.
- **Chemical equilibrium:** when the chemical composition of a system does not change with time, i.e., no chemical reactions occur.

Processes and Cycles

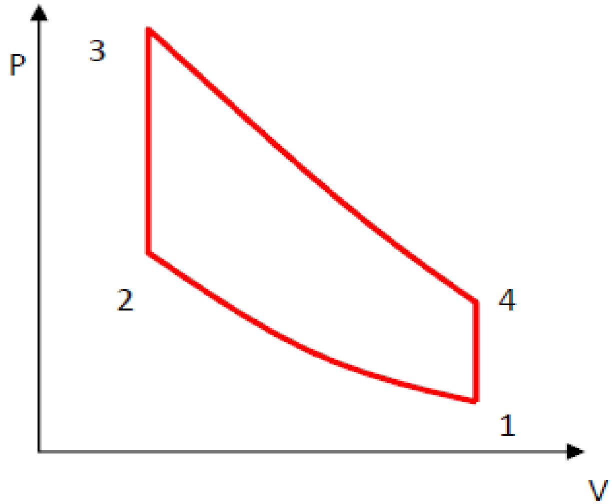
- ***Process:*** Any change that a system undergoes from one equilibrium state to another.



- ***Process path:*** The series of states through which a system passes during a process is called the path of the process.

- ***Quasi-Equilibrium Process:*** A sufficiently slow process that allows the system to adjust itself internally so that properties of the system are constant throughout.

- ***The cycle:*** A system is said to have undergone a cycle if it returns to its initial state at the end of the process.



A four-process cycle in a P-V diagram.

➢ Energy:-

❑ ***Macroscopic forms of energy*** *are those a* system possesses with respect to some outside reference frame:

➢ ***Kinetic Energy (KE):***

The energy that a system possesses as a result of its motion relative to some reference frame. $KE = mv^2/2$

➢ ***Potential Energy (PE):***

The energy that a system possesses as a result of its elevation in a gravitational field. $PE = mgz$

❑ ***Microscopic forms of energy*** ***are those*** related to the *molecular structure and the* degree of *molecular activity of a system.*

➢ ***Internal Energy:***

The sum of all the microscopic forms of energy – *U.*

It refers to the *invisible microscopic energy on the atomic* and molecular scale.

Total Energy (E): =

Macroscopic forms of energy + Microscopic forms of energy

$$E = KE + PE + U$$
$$= mv^2/2 + mgz + U$$

➢ Temperature:-

➢ A measure of the "*hotness*" *or* "*coldness*" *of a body.*

➢ Energy always flows from the *hotter to the colder body.*

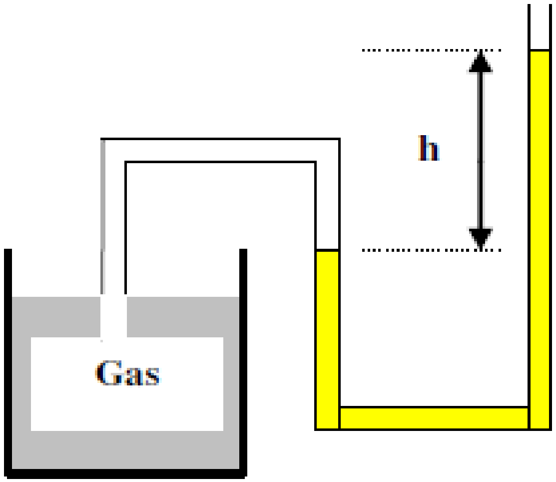
➢ ***The zero law of thermodynamic*** states that when two bodies have equality of temperature with a third body, they have equality of temperature with each other.

➢**Temperature Scales:** Temperature Scale in the SI unit is

- ➢ ***the Celsius scale*** (formerly called the Centigrade scale). On the Celsius Scale, the ice and steam points are assigned the values of 0 and 100 °C.
- ➢ ***the Kelvin scale*** (K). The lowest temperature on the Kelvin scale is 0 K. $T(K) = T(°C)+273.15$

➢The Ideal-Gas Temperature Scale

Is identical to the Kelvin scale.



- The temperatures on this scale are measured using a *constant-volume gas thermometer, which is a rigid* vessel filled with a gas usually hydrogen or helium at low pressure.

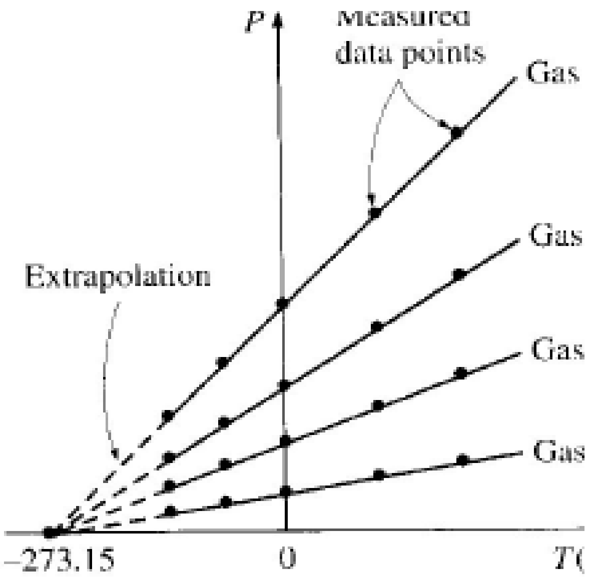
- *Principle: The temperature of a gas* of fixed volume varies linearly with pressure at sufficiently low *P.*

$$T\,(°C) = a + b\,P, \quad V = constant$$

$$a = -273.15$$

Absolute temperature scale:

$$T\,(K) = b\,P$$



➢ Pressure:-

❑Pressure is the force exerted by a fluid per unit area.

Pressure = Force/Area =F / L^2

1 Pa = 1 N/m^2 (SI Unit)
1 bar = 10^5 Pa = 100 kPa =0.1 MPa
1 atm = 1.01325 bar

➢ *Absolute Pressure:*

Is the actual pressure at a given position, *and it is measured* relative to absolute vacuum.

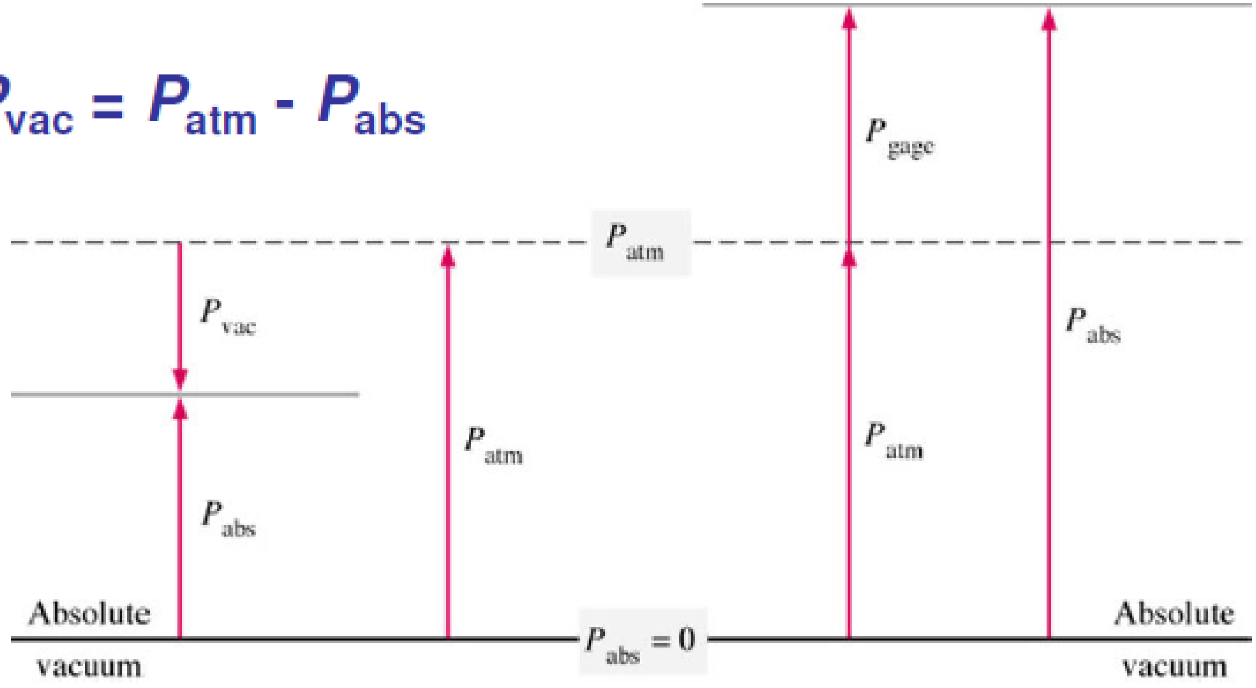
➢ *Measured Pressure:*

Pressure measured relative to the absolute pressure of the atmosphere

(a)Gauge pressure ***(b) Vacuum pressure***

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

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



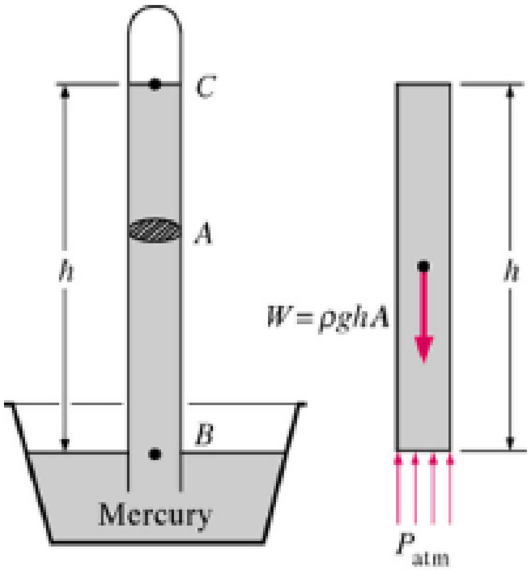
$$P_{gauge} = P_{abs} - P_{atm}$$

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

Pressure measurements :

❑ ***Barometers:–*** **Atmospheric pressure**

$$P_B = P_{atm}$$
$$P_C = 0$$
$$P_{atm} = \rho . g . h$$



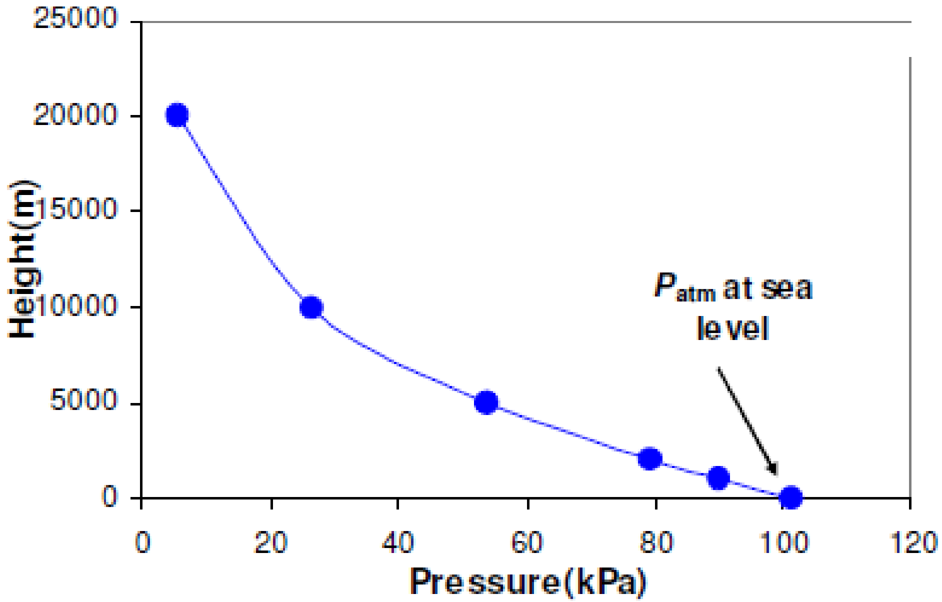
❖ ***The standard atmospheric pressure = 760 mmHg***

❖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) is:

$$P_{atm} = 760\ mmHg$$
$$P_{atm} = 13{,}595\ kg/m^3 \times 9.807\ m/s^2 \times 0.760\ m$$
$$= 101.328\ \text{kPa}$$

Variations of P_{atm} *with altitude:-*

❖ *Atmospheric pressure decreases with elevation due to gravity.*



Consequences of high elevation:

✓ Longer runway for airplanes at higher altitudes because…………………….

✓ Larger chests and lungs for people living at higher elevation because……..

✓ Lower boiling point at higher elevation because……………………………

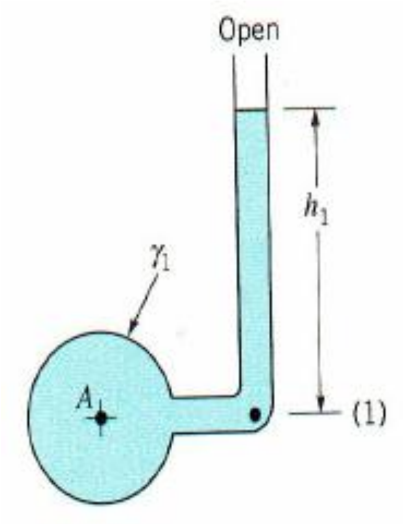
✓ Nose bleeding because……………………………………………………...

❑ ***Manometers*:**

1) ***Piezometer Tube***

The simplest type of manometer consists of a vertical tube, open at the top, and attached to the container in which the pressure is desired.

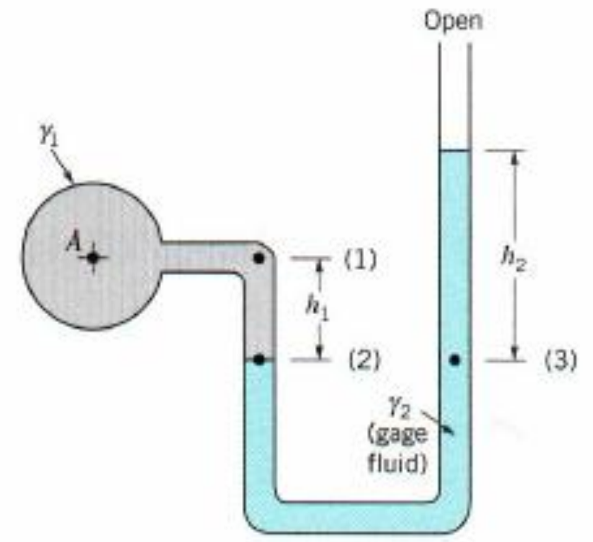
$$P_A = P_{atm} + \rho g h_1$$



❖The fluid in the container is liquid, otherwise……………………………..
❖The pressure in the container is relatively small, otherwise………………
❖The pressure in the container is greater than atmospheric pressure, otherwise
………………………………………………………………………...

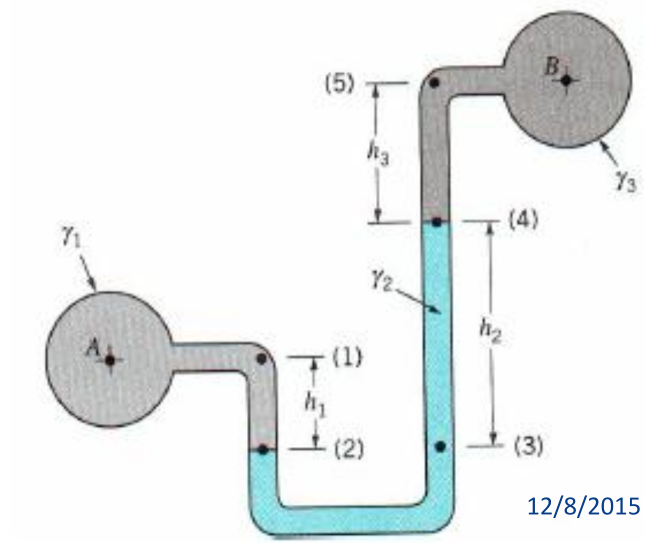
2) *U-Tube Manometer*

a) **Pressure in a gas tank:**



$$P_2 = P_3$$
$$P_A + \rho_1 g h_1 = \rho_2 g h_2 + P_{atm}$$
$$P_A + \rho_1 g h_1 - \rho_2 g h_2 - P_{atm} = 0$$
$$P_A = \rho_2 g h_2 + P_{atm} \qquad (\rho_1 = 0)$$

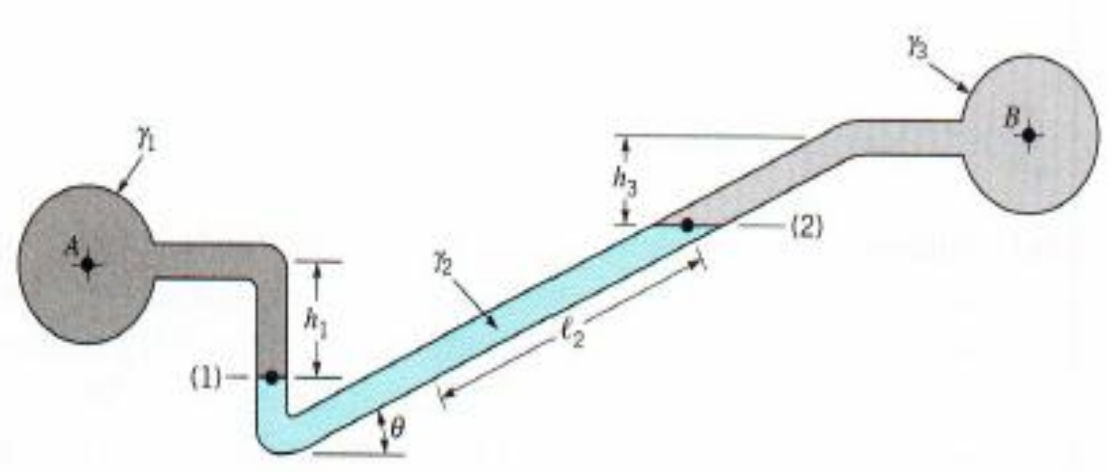
b) **Pressure difference between two tanks:**



$$P_A + \rho_1 g h_1 - \rho_2 g h_2 - \rho_3 g h_3 - P_B = 0$$
$$P_A - P_B = \rho_2 g h_2 - \rho_1 g h_1 + \rho_3 g h_3$$

3) *Inclined-Tube Manometer*

- One leg of the manometer is inclined at an angle θ .
- It is used to measure small pressure changes.



$$P_A + \rho_1 g h_1 - \rho_2 g\ l_2 \sin\Theta - \rho_3 g h_3 = P_B$$

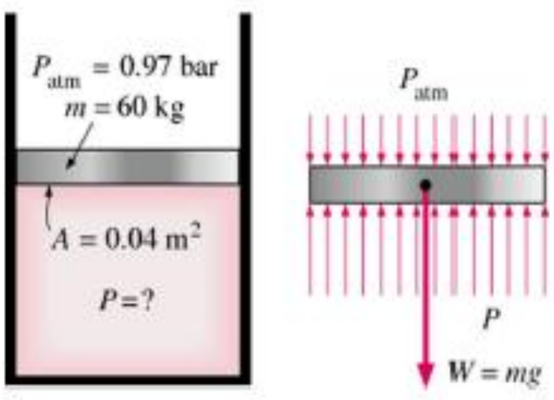
If $\rho_1 = \rho_3 = 0$

$$\boldsymbol{P_A - P_B = \rho_2 g\, l_2 \sin\Theta}$$

Example 1.

The piston of a vertical piston-cylinder device containing a gas has a mass of 60 kg and a cross section area of 0.04 m^2. The local atmospheric pressure is 0.97 bar. Assume that the initial volume of enclosed vessel is 0.08 m^3 and the gravitational acceleration is 9.81 m/s^2.

Determine: the pressure inside the cylinder.



Solution:

$$PA = P_{atm}A + W$$

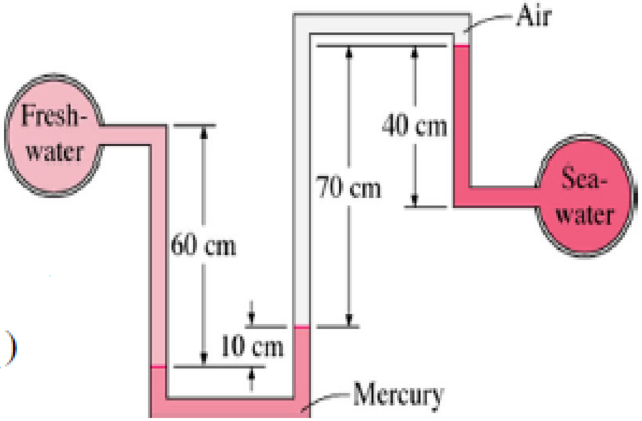
$$P = P_{atm} + \frac{mg}{A}$$

$$P = 0.97\text{ bar} + \frac{(60\text{ kg})(9.81\text{ m/s}^2)}{0.04\text{ m}^2}\left(\frac{1\text{ N}}{1\text{ kg.m/s}^2}\right)\left(\frac{1\text{ bar}}{10^5\text{ N/m}^2}\right) = 1.12\,bars$$

Example 2.

Freshwater and seawater flowing in parallel horizontal pipelines are connected to each other by a double U-tube manometer. Determine the pressure difference between the two pipelines. The densities of seawater and mercury are given to be r_{sea} = 1035 kg/m^3 and r_{Hg} = 13,600 kg/m^3. The density of water is r_w =1000 kg/m^3. Can the air column be ignored in the analysis?

Solution:



$$P_w + \rho_w g h_w - \rho_{Hg} g h_{Hg} - \rho_{air} g h_{air} + \rho_{sea} g h_{sea} = P_{sea}$$

$$P_w - P_{sea} = -\rho_w g h_w + \rho_{Hg} g h_{Hg} - \rho_{sea} g h_{sea} = g(\rho_{Hg} h_{Hg} - \rho_w h_w - \rho_{sea} h_{sea})$$

$$P_w - P_{sea} = (9.81\,\text{m/s}^2)[(13600\,\text{kg/m}^3)(0.1\,\text{m}) - (1000\,\text{kg/m}^3)(0.6\,\text{m}) - (1035\,\text{kg/m}^3)(0.4\,\text{m})]\left(\frac{1\,\text{kN}}{1000\,\text{kg}\cdot\text{m/s}^2}\right)$$

$$= 3.39\,\text{kN/m}^2 = \mathbf{3.39\,kPa}$$