Processes and Process Variables

- Process: Any operation or series of operations by which a particular objective is accomplished.

  e.g. Operations that cause a physical or chemical change in a substance or mixture.

The material entering a process: input, feed

The material leaving a process: output, product

If there are multiple steps, each will be a process unit with its own process streams (I,O)

You design (formulation of a flowsheet and specifications) or operate (day-to-day running of process) a process.

VARIABLES

- Mass and Volume:
- Density = mass / volume
- Specific volume = volume occupied by unit mass = $1/\rho$ (density)

- If ρ = 1.595 g/cm^3, volume = 20.0 cm^3,
- $\rightarrow$ mass = 20.0 cm^3 1.595 g/cm^3 = 31.9 g

- Specific gravity = $\rho_{subs.} / \rho_{ref.subs.}$ (at specific conditions) $\rightarrow SG = \rho / \rho_{ref.}$
- $\rho_{ref} = \rho_{H2O(l)}$ (4^{o}C) = 1.000 g/cm^3 = 62.43 lb$_m$/ft^3
- SG = 0.6 (20^o/4^o) SG = 0.6 at 20^{o}C with reference to 4^{o}C

Example:

- Calculate the density of mercury in lb_m/ft^3, if its SG=13.546 $20^o/40^o$
- Calculate the volume in ft^3 occupied by 215 kg of mercury.

ρ_{Hg} = 13.546 (62.43 lb_m/ft^3) = 845.7 lb_m/ft^3

$V = m / \rho_{Hg}$

= 215 kg (1lb_m / 0.454 kg) (1 ft^3 / 845.7 lb_m)

= 0.560 ft^3

For solids and liquids $\rho \neq \rho(T,P)$

For gases it is obvious

For mercury ρ is depended on T:

$V(T) = V_o (1 + 0.18 \times 10^{-3} T + 0.0018 \times 10^{-6} T^2)$

3.1.1 Example: m = 215 kg, V = 0.560 ft^3 at 20°C

$V(T) = V_o (1 + 0.18 \times 10^{-3} T + 0.0018 \times 10^{-6} T^2)$

What volume would the mercury occupy at 100°C?

(1) If it is contained in a cylinder (D=0.25 in), what change in height would be observed as the mercury is heated from 20°C to 100°C?

$V(100^oC)=V_o[1+0.18\times10^{-3}(100)+0.0018\times10^{-6}(100)^2]$

$V(20^oC)=V_o[1+0.18\times10^{-3}(20)+0.0018\times10^{-6}(20)^2]$

$= 0.560\ ft^3$

Solving for V_0 from the 2nd equation and substituting it into the 1st yields.

→ $V(100^oC) = 0.568\ ft^3$

$Vcyl = \pi D^2/4$

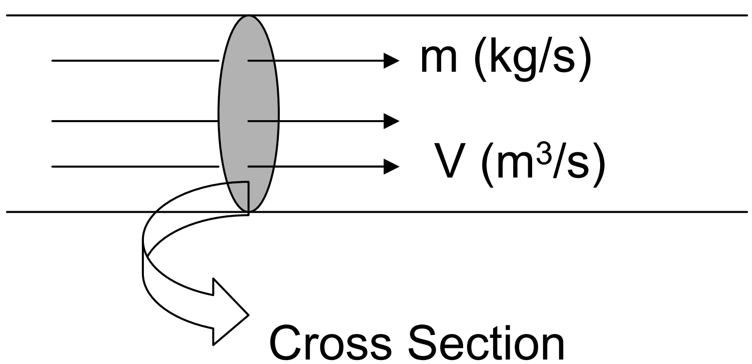
$H(100^oC) – H(20^oC) = [V(100^oC) – V(20^oC)] / (\pi D^2/4)$

=23.5 ft

Flow Rate

Mass an Volumetric Flow Rate:

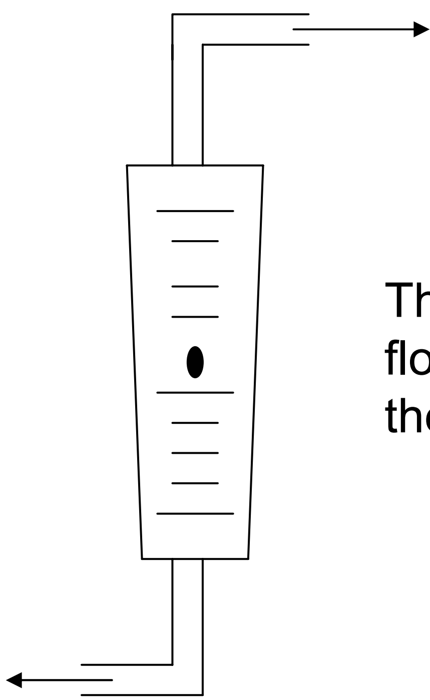
- Material move between process units, between a production facility and a transportation depot. The rate at which a material is trasported through a process line is the flow rate. Blood flows in the arteries with a specific flow rate.
- Mass flow rate → (mass/time)
- Volumetric flow rate → (volume/time)



$$\rho = \frac{m}{V} = \frac{\dot{m}}{\dot{V}} \qquad \dot{n} = \frac{n}{t}$$

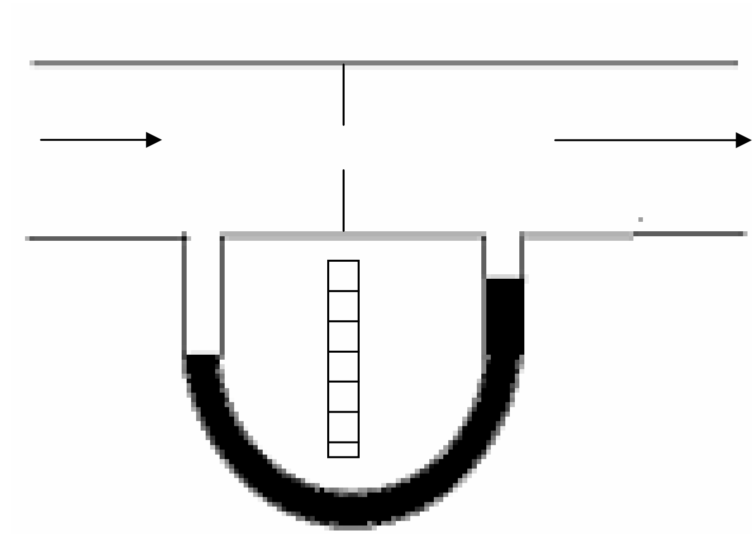
Flow Rate Measurement

- Flowmeter: A device that reads continiously flow rate in the line.



The larger the flow rate the higher the float rises

Rotameter



Fluid pressure drops from the upstream to the downstream

Orificemeter

- Chemical Composition: The properties of a mixture depend on mixture compositions.
- Moles and Mole Weight: A g-mole (or mol in SI units) of a species is the amount of that species whose mass in grams is numerically equal to its MW. e.g. CO has a MW of 28.
- 1 mol of CO contains 28 g
- 1Ib-mole CO contains 28 Ib_m
- 1 ton-mole CO contains 28 tons
- e.g. NH_3 has a MW of 17.
- 34 kg of ammonia is;

34 kg NH_3 (1 kmol NH_3/17 kg NH_3) = 2 kmol NH_3

- ***Example: Conversion between Mass and Moles***

- How many of each of the following are contained in 100 g CO_2 (M=44.01) (a) mol CO_2; (b) Ib-moles CO_2; (c) mol C

- 100 g (1 mol CO_2/44.01 g CO_2) = 2.273 mol CO_2

- 2.273 mol CO_2 (1 Ib-mol/453.6 mol)=5.011 10^{-3} Ib-mole CO_2

- 2.273 mol CO_2 (1 mol C / 1 mol CO_2)=2.273 mol C

- Calculate the flow rate in kmol CO_2/h if flow rate = 100 kg/h CO_2
- 100 kg CO_2 /h (1 kmol CO_2 / 44.01 kg CO_2) = 2.27 kmol CO_2/h

Masses and Mole Fractions and Average Molecular Weight

- Process input or output streams can contain mixtures of liquids or gases, solutions of one or more solutes in a solvent. You need mass fraction and mole fraction to define the compositions:
- Mass fraction; x_A = mass of A / total mass
- Mole fraction; y_A= moles of A / total moles

- Example: A solution contains 20% X and 25% Y by mass.
- Calculate the mass of X in 220 kg of solution:

  220 kg solution 0.20 kg X / kg solution = 44 kg X
- Calculate the mass flow rate of A in stream flowing at a rate of 53 lb_m/h:

  53 lb_m/h 0.20 lb_m X/lb_m solution = 10.6 lb_m X/h

- The Average Molecular Weight

$$\overline{M} = y_1 \cdot M_1 + y_2 \cdot M_2 + \text{.........} = \sum_{allcomp.} y_i \cdot M_i$$

$$\frac{1}{\overline{M}} = \frac{x_1}{M_1} + \frac{x_2}{M_2} + \text{.........} = \sum_{allcomp.} \frac{x_i}{M_i}$$

Where;

x_i = Mass fraction

y_i = Mole fraction

M_i = Molecular weight of component

Concentration

- Mass concentration = mass of a component / volume of the mixture

- Molar concentration = moles / volume

- Molarity = molar concentrationof solute / volume of solution

- Parts per million (ppm), and
- parts per Billion (ppb) are used to express the concentration of trace species.

- $ppm_i = y_i \times 10^6$
- $ppb_i = y_i \times 10^9$

- Example: In normalş living cells, the nitrogen requirement for the cells is provided from protein metabolism. When individual cells are commercially grown, $(NH_4)_2SO_4$ is usually used as the source of nitrogen. Determine the amount of $(NH_4)_2SO_4$ consumed in a fermentation medium in which the final cell concentration is 35 g/L in a 500 L volume of the fermentation medium. Assume cells contain 9 wt% N, and that $(NH_4)_2SO_4$ is the only N source.

- Basis: 500 L solution containing 35 g/L cell concentration,

$$500L \frac{35gcell}{L} \frac{0.09gN}{1g \quad cell} \frac{1gmolN}{14gN} \frac{1gmolNH4SO4}{1gmolN} \frac{132g(NH4)2SO4}{1gmol(NH4)2SO4)}$$

= 14,850 g $(NH_4)_2SO_4$

A solution of HNO_3 in water has a specific gravity of 1.10 at 25°C. The concentration of HNO_3 is 15 g/L of solution. What is the;

a) Mole fraction of HNO_3 in the solution?
b) ppm of HNO_3 in the solution? (Take 1 L and 100 g of solution)

Basis: 1 L →

(15 g HNO_3/1 L solution) (1 L/1000 cm^3) (1 cm^3/1.10 g solution)

= 0.01364 g HNO_3/g solution

(Assume SG = $\rho_{solution}$)

Basis: 100 g solution;
The mass of water in the solution is:
100 – 1.364 = 99.986 g H_2O

	g	MW	g-mole	Mol frac.
HNO_3	1.364	63.02	2.164×10^{-4}	3.9×10^{-5}
H_2O	99.986	18.016	5.550	1

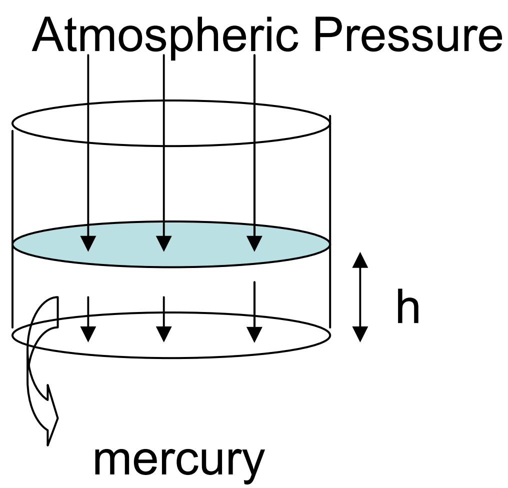
b)Mass fraction is 0.01364 or

= $13{,}640/10^6$ or

= 13,640 ppm

Pressure

- A pressure is the ratio of a force to the area on which the force acts. Units are N/m^2 (Pa), $dynes/cm^2$, lb_f/in^2
- Pressure is defined as the "normal (perpendicular) force per unit area"



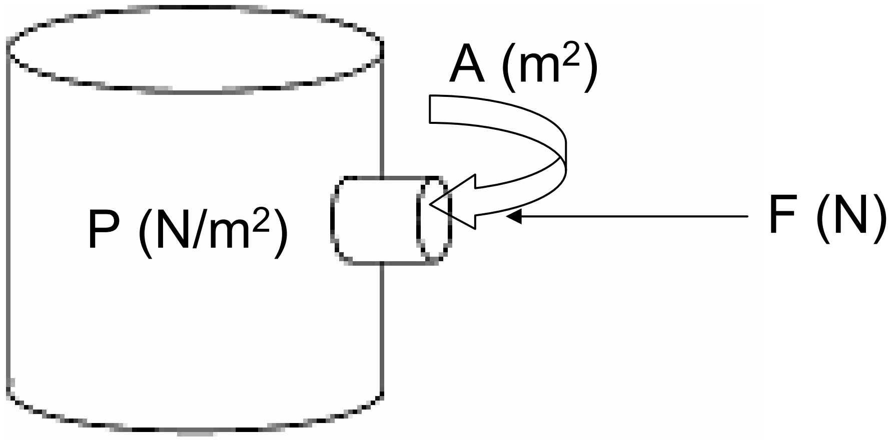
$$P = \frac{F}{A} = \rho \cdot g \cdot h + P_0$$

P = static pressure

ρ = density of fluid

g = gravity

P_0 = pressure at the top of the fluid



F (N) : minimum force that would be exerted in the hole to keep the fluid from emerging

A pressure may be expressed as a "head" of a particular fluid; the height of a hypothetical column of this fluid exerting the same pressure at its base if the pressure at the top were zero. e.g. 76 cm of mercury (76 cm Hg). The equivalence between a pressure (P) and its corresponding head P_h is given as;

$$P\ (\text{force/area}) = \rho_{fluid}\ g\ P_h\ (\text{head of fluid})$$

- Example: Express 2.0 x 10^5 Pa in terms of mmHg.

  ρ_{Hg} = 13.6 x 1000 kg/m^3 = 13600 kg/m^3

  g = 9.807 g/s^2

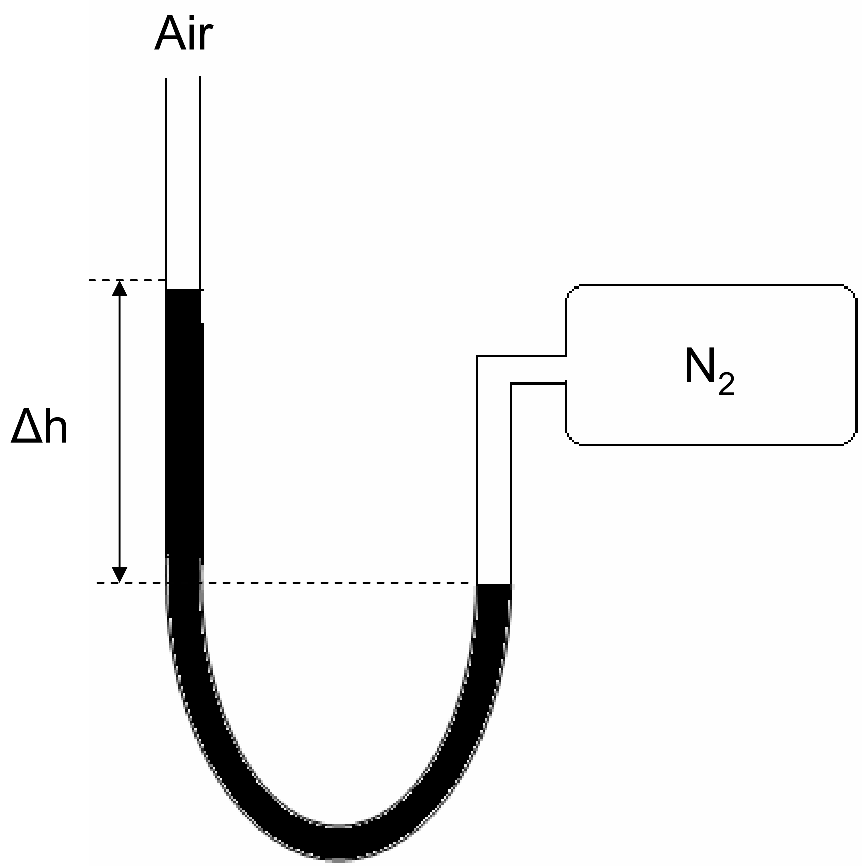
$$P_h = \frac{P}{\rho_F \cdot g} = 2 \times 10^5 \cdot \frac{N}{m^2} \cdot \frac{m^3}{13600 \cdot kg} \cdot \frac{s^2}{9.807 \cdot m} \cdot \frac{1 \cdot kg \cdot m / s^2}{N} \cdot \frac{10^3 mm}{m}$$

$$= 1.50 \times 10^3 \, mmHg$$

P_h (mmHg) = P_0 (mmHg) + h (mm Hg)

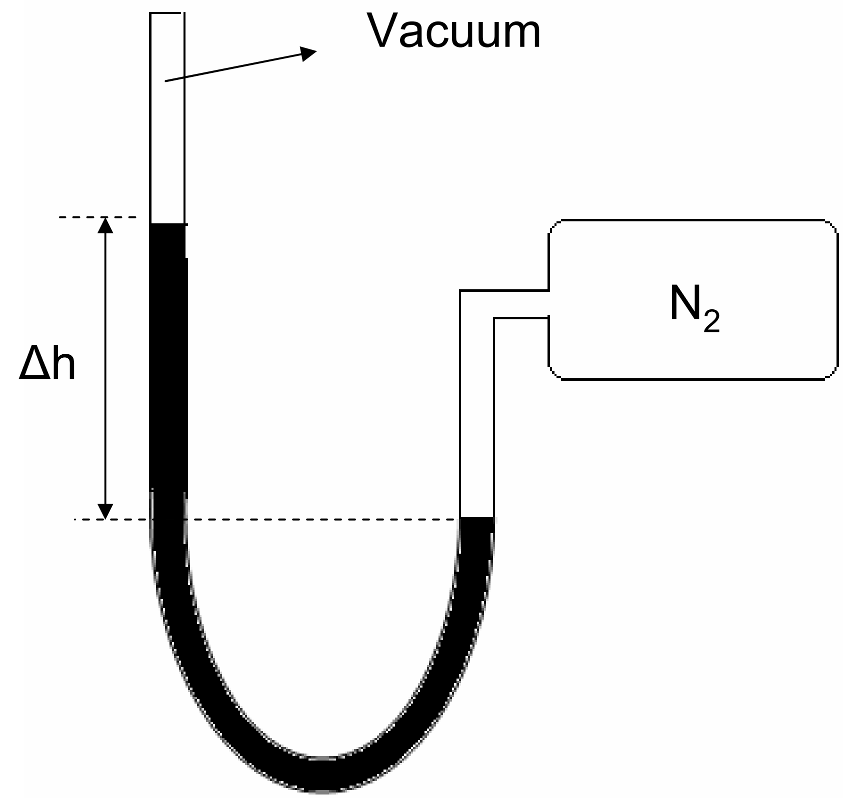
Atmospheric, Absolute, and Gauge Pressure

- Atmospheric pressure at sea level, 760 mmHg = 1 atm.
- The fluid pressures are "absolute" pressures if a zero pressure corresponds to a perfect vacuum. Many devices measure the "gauge pressure" of a fluid or the pressure relative to the atmospheric pressure.
- $P_{gauge} = 0 \rightarrow P_{absolute} = P_{atmospheric}$
- $P_{absolute} = P_{gauge} + P_{atmospheric}$
- psia and psig are commonly used to denote absolute and gauge pressures in lb_f/in^2



Open end monometer

Relative (gauge) Pressure

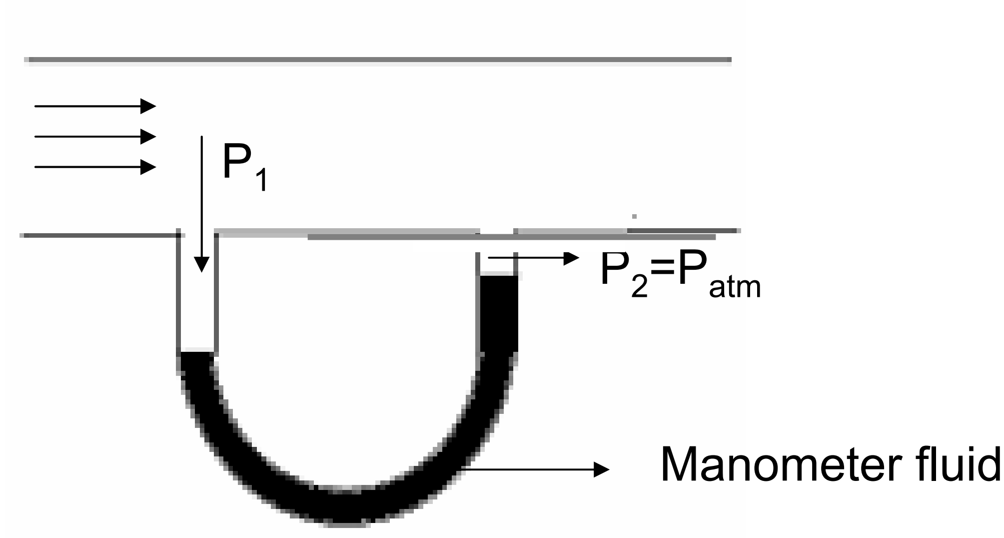


Absolute Pressure

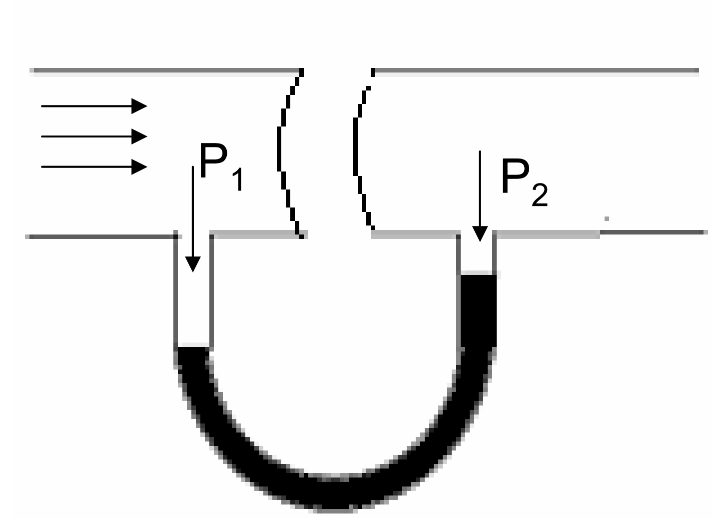
Fluid Pressure Measurement

- Elastic-element method-Bourden tubes
  7000 atm < P <0
- Liquid-column methods-manometers

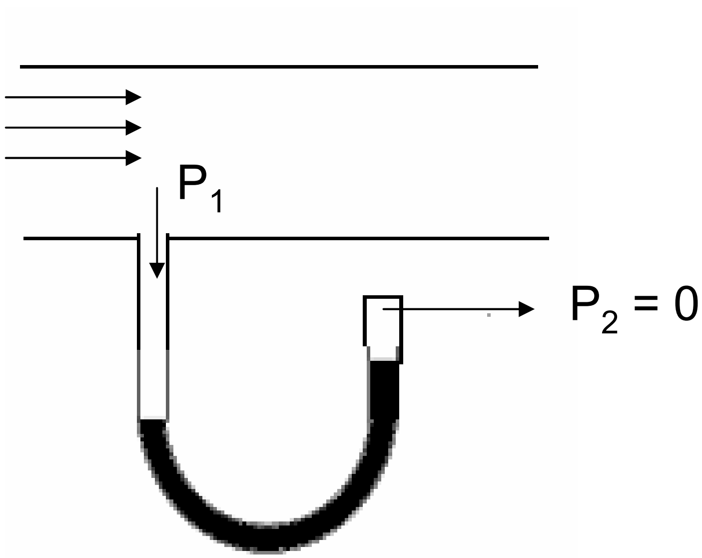
  P < 3 atm → accurate
- Electrical Methods-Strain gauges



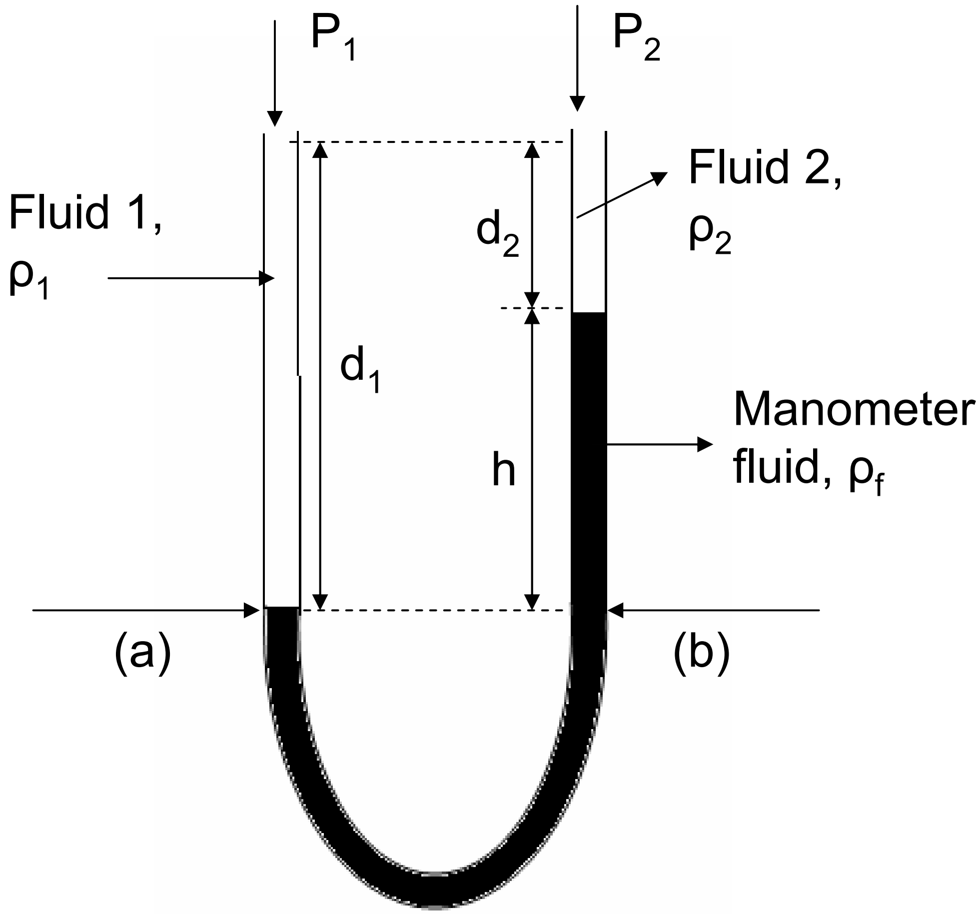
Open-end



Differential



Sealed-end



General manometer equation:

$$P_1 + \rho_1 g d_1 = P_2 + \rho_2 g d_2 + \rho_F g h$$

If $\rho_1 = \rho_2 = \rho$; $P_1 - P_2 = (\rho_F - \rho) g h$ (Differential manometer equation)

If both fluids are gases $\rho_F >> \rho$

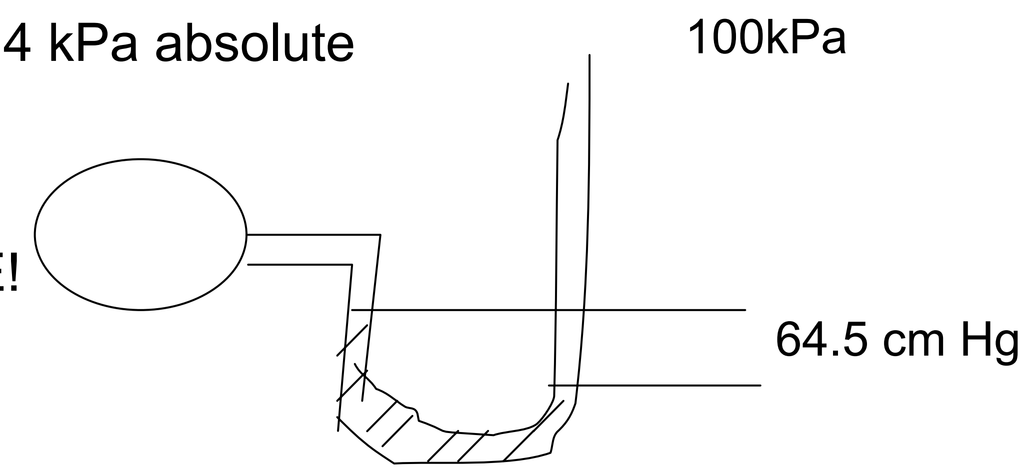
$\rightarrow P_1 - P_2 = \rho_F g h$

- Small animals like mice can live at reduced air pressures down to 20 kPa absolute. In a test, a mercury manometer attached to a tank, reads 64.5 cm Hg and the barometer reads 100 kPa. Will mice survive?

$$P = 100\text{ kPa} - 64.5\text{ cmHg}\left(\frac{101.3\text{ kPa}}{76\text{ cmHg}}\right)$$

$$= 100 - 86 = 14\text{ kPa absolute}$$

MICE WILL DIE!



Temperature

- It is a measure of energy (mostly kinetic) of the molecules in a system. Since kinetic energy cannot be measured directly, T must be determined indirectly by measuring some phisical property of the substance whose value depends on T.
- Electrical resistance of a conductor (resistance thermometer), voltage at the junction of two dissimilar metals (thermocouple), spectra of emitted radiation (pyrometer), and volume of a fixed mass of a fluid (thermometer)

- Rankine-Fahrenheit Scale $\Delta°F = \Delta°R$
- Kelvin-Celcius Scale $\Delta°C = \Delta°K$
- $\Delta°C / \Delta°F = 1.8$
- $\Delta°K / \Delta°R = 1.8$
- $T(°K) = T(°C) + 273.15$
- $T(°R) = T(°F) + 459.67$
- $T(°R) = 1.8\ T(°K)$
- $T(°F) = 1.8\ T(°C) + 32$