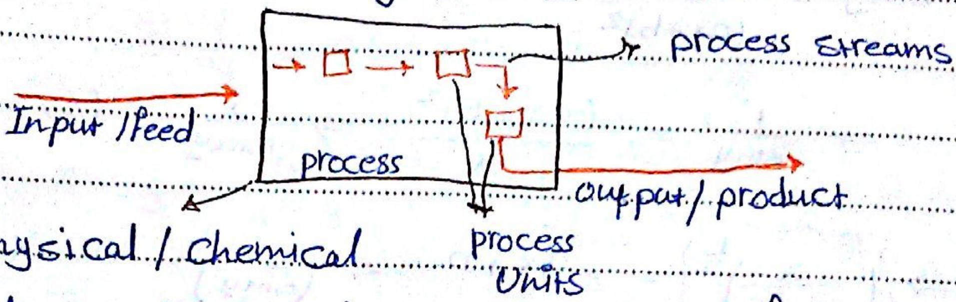
12 /oct /2015

Chapter 3 ⤳ Process and Process Variables.

Process: any operation or series of operations by which a particular objective is acomplished.

* In chemical Engineering



physical / chemical changes in a substance / mixture of substances.

Chemical Engineer

Design of a process:	Operate a process day - by - day running of the process
Formulation of a process and specifications of industrial process units (reactor / separation unit, heat exchange, ... etc)	(troubleshooting

1- Mass and Volume:

density = mass per unit voulme $[=] \frac{M}{L^3}$ → g/cm^3, kg/m^3, $\frac{lbm}{ft^3}$

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* specific volume = volume occupied by unit mass

$= \frac{1}{density}$ [=] $\frac{L^3}{M}$ → cm^3/g, m^3/kg, ft^3/lbm

* Liquid and solids : density ≠ f(p), changes very slightly w/ temperature.

e.g. → a) 0°C , $\rho = 0.99988\ g/cm^3$

b) 4°C , $\rho = 1.00000\ g/cm^3$

c) 100°C , $\rho = 0.95838\ g/cm^3$

* Specific gravity = ratio of substance density ρ to the density of a reference substance at specific conditions , ρ_{ref}

$$SG = \frac{\rho}{\rho_{ref}}$$

* ρ_{ref} is usually that of water at 4°C (For Liq and solids)

e.g. $SG = 0.6\ \frac{20°}{4°}$ = specific gravity of that substance at 20°C with ref to water at 4°C is 0.6

ρ_{ref} (water @ 4°C) $= 1.000\ g/cm^3$

$= 1000.0\ kg/m^3$

$= 62.43\ lbm/ft^3$

TYS – Pg # 44 ⇝

Q28: SG = 0.50 $\rho = ?$ g/cm³

$\rho = SG * \rho_{ref} = 0.5 * 1.000 = 0.500$ g/cm³

specific voulme $= \frac{1}{\rho} = \frac{1}{0.50} = 2$ cm³/g

$\rho = 0.50 * 62.43 = 31.22$ lbm/ft³

$V = 3$ cm³ , $m = ?$

$$m = \rho V = \frac{0.5g}{cm^3} \Big| 3cm^3 = 1.50g$$

$m = 18g$, $V = ?$

$$V = \frac{m}{\rho} \Rightarrow \frac{18g}{} \Big| \frac{cm^3}{0.500g} = 36 cm^3$$

2- Flow rates

A. Mass and Volumetric Flow rate:

Flow rate: rate at which a Material is transported

mass Flow rate   volumetric Flow rate

$[=] \frac{M}{t}$ $(\dot{m})$ $[=] \frac{L^3}{t}$ $(\dot{V})$

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

TYS – Pg # 46 ⇝

Q1 ⇝ $\dot{m} = 6.59$ g/s , $\rho = 0.659$ g/cm³ , $\dot{V} = ?$

$$\dot{V} = \frac{\dot{m}}{\rho} = \frac{6.95\cancel{g}}{s} \Big| \frac{cm^3}{0.659\cancel{g}} = 10.0 \ cm^3/s$$

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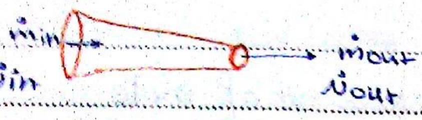
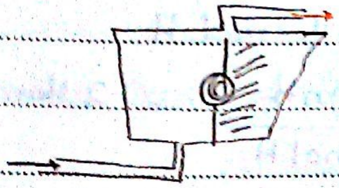
Q3 ~



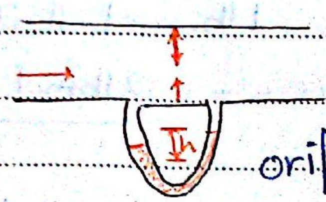
$$\left.\begin{aligned} \dot{m}_{in} &= \dot{m}_{out} \\ e_{in}\,\dot{v}_{in} &= e_{out}\,\dot{m}_{out} \end{aligned}\right] \text{if } e_{in} = e_{out} \Longrightarrow \dot{v}_{in} = \dot{v}_{out}$$

B. Flow rate measurement :-

Using Flow meter (device)



rotameter



orifice meter

3. Chemical Composition :

needed because most materials are in mixture.

physical properties $\longleftrightarrow$ composition.

* Molecular weight = $\sum$ atomic weight = M

SI [gram-mole = g-mole = mol.
   Kg-mole = kmol

Amer [lb-mol , ton-mol

e.g ~ $M(NH_3) = 14 + 1*3 = 17$ g/mol

Kg/Kmol

lbm/lbmol

* $\frac{g}{lbm} = \frac{mol}{lbmol}$ $\left[\frac{Kg}{lbm} = \frac{Kmol}{lbmol}\right]$

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$m = M * N$ N = # of mole

$\dot{m} = M * \dot{N}$ $\dot{N}$ = molar Flow rate

TYS - Pg #49 :-

Q3:- 1 lb-mol H_2O, how many lb-mol, lbm of H_2 and H are in there?

1 lb-mol H_2O has 2 lb-mol H

$$= \frac{2\,\text{lbmol H} \mid 1\,\text{lbm H}}{\mid 1\,\text{lbmol H}} = 2\,\text{lbm H}$$

lbmol H_2O has 1 lbmol H_2

$$= \frac{\text{lbmol } H_2 \mid 2\,\text{lbm } H_2}{\mid \text{lbmol } H_2} = 2\,\text{lbm } H_2$$

Q4:- 2 Kmol C_3H_8 = ? g-mole = ? Kg

$$\frac{2\,\text{Kmol } C_3H_8 \mid 10^3\,\text{mol}}{\mid 1\,\text{kmol}} = 2000\,\text{mol } C_3H_8$$

$m(kg) = M \cdot N(Kmol)$

$M(C_3H_8) = 3 * \underbrace{12}_{C} + 8 * \underbrace{1}_{H} = 44\,\text{Kg/mol}$

$$m = \frac{44\,\text{Kg} \mid 2\,\text{Kmol}}{\text{Kmol} \mid} = 88\,\text{Kg}.$$

Q5 ⇝ $\dot{m}(H_2) = 100\,\text{Kg/h}$, molar flowrate mol/h?

$\dot{m} = M \cdot \dot{N}$

$$\dot{N} = \frac{\dot{m}}{N} = \frac{100\,\text{Kg} \mid \text{Kmol} \mid 10^3\,\text{mol}}{h \mid 2\,\text{Kg} \mid \text{Kmol}} = 50 * 10^3\,\text{mol/h}$$

Subject: ....

* Mass Fraction and Mole Fraction :-

Mass Fraction = $x_A = \dfrac{\text{mass of A}}{\text{total mass}}$

percent by mass $= 100 * x_A$

Mole Fraction = $y_A = \dfrac{\text{moles of A}}{\text{total moles}}$

mole percent $= 100 * y_A$

$\boxed{*}$ mass Fraction $\xleftrightarrow[\text{Calculations}]{\text{basis of}}$ mole Fraction

TYS - pg # 52 :-

Q1 ~ $M(H) = 1$, $M(Br) = 80$

a) x_{Br} b) y_{Br} in pure HBr ?

Basis of calculations : n : 1 mol HBr

= 1 mol H + 1 mol Br

$$x_{Br} = \frac{m_{Br}}{m_{total}} = \frac{\overset{\text{mol Br}}{1} * \overset{\text{g/mol Br}}{80}}{\underbrace{1*1}_{H} + \underbrace{1*80}_{Br}} = \frac{80}{81} \text{ g Br / g HBr}$$

$$y_{Br} = \frac{N_{Br}}{N_{total}} = \frac{1}{1+1} = 0.5 \text{ mol Br / mol HBr}$$

Q2 :-

100 lbm A/min → [ ] →
300 lbm B/min

$\dot{m} = M \cdot \dot{N}$

$M_A = 2$, $M_B = 3$

$\dot{m}_A = 100$ lbm A/min

$$x_A = \frac{100}{100+300} = 0.25 \text{ lbm A / lbm}$$

$$y_A = \frac{100/2}{100/2 + 300/3} = \frac{50 \text{ lbmol A}}{50 + 100} = 0.33 \text{ lbmol A / lbmol}$$

$\dot{n}_B = 300/3 = 100$ lbmol B/min

$\dot{m}_{total} = 400$ lbm/min

$$\dot{n}_{total} = \overset{A}{\frac{100}{2}} + \overset{B}{\frac{300}{3}} = 150 \text{ lbmol/min}$$

* Average Molecular Weight ⇝

$\bar{M} = \sum y_i M_i$ ⇒ y_i = mole Fraction

$\frac{1}{\bar{M}} = \sum \frac{x_i}{M_i}$ ⇝ x_i = mass Fraction

* **P 3-17** ⇝

25 mol % N_2, 75 mol % H_2 → [NH_3 reactor] → NH_3 3000 kg/h

Find ⇝ m_{N_2} = ??

$M(N_2) = 28$, $M(H) = 2$

$\dot{m}_{total}$

method 1:

$\boxed{y_i \xrightarrow{\bar{M}} x_i}$

↓

$\boxed{\dot{m}_i = x_i \, \dot{m}_{total}}$

$\dot{m}_{N_2}$

$\dot{m}_i$

method 2:

$\boxed{\dot{m}_{total} \xrightarrow{\bar{M}} \dot{n}_{total}}$

↓

$\boxed{\dot{n}_i = y_i * \dot{n}_{total}}$

↓

$\boxed{\dot{m}_i = M_i * \dot{n}_i}$

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Method 1 ⇝

To convert $y_i \longrightarrow x_i$, we need a basis ⇝

Basis : 100 mol mixture.

	N_2	H_2
y_i	0.25	0.75
n_i	$0.25 * 100 = 25$ $\downarrow * 28$ (M_{N_2}) 700g	75 $\downarrow * 2$ (M_{H_2}) 150g
	$m_{total} = 850g$	
$x_i = \frac{m_i}{m_{total}}$	$\frac{700}{850} = 0.82$	$\frac{150}{850} = 0.18$

$$\dot{m}_{N_2} = x_{N_2} * \dot{m}_{total}$$
$$= 0.82 * 3000$$
$$= 2470 \ kg_{N_2}/h$$

/ /

Method (2) $\bar{M} = \sum y_i M_i$

$= (0.25)(28) + (0.75)(2)$

$= 8.5 \text{ g/mol}$

$\dot{n}_{total} = \dfrac{\dot{m}_{total}}{\bar{M}} = \dfrac{3000}{8.5} = 353 \dfrac{kmol}{h}$

$\dot{n}_{N_2} = y_{N_2} * \dot{n}_{total} = 0.25 * 353 = 88.2 \dfrac{kmol\ N_2}{h}$

$\dot{m}_{N_2} = \dot{n}_{N_2} * M_{N_2} = (88.2)(28) = 2470 \text{ kg } N_2/h$

* P3-19 sol

mixture : 10 mol % ethylalcohol $= y_1$ $M_1 = 46$

75 mol % ethylacetate $= y_2$ $M_2 = 88$

15 mol % acetic acid $= y_3 \Rightarrow M_3 = 60$

a) $x_i = ??$ b) $\bar{M} = ??$ c) if $n_2 = 25$ mol , $m_{total} = ?$

Basis $\Rightarrow$ 100 mol

	(1)	(2)	(3)
y_i	0.10	0.75	0.15
n_i	10	75	15
m_i	$10*46 = 460$	$75*88 = 6600$	$15*60 = 900$
$x_i = \dfrac{m_i}{m_{total}}$	$\dfrac{460}{7960} = 0.058$	0.38	0.11

$\rightarrow m_{total} = \sum m_i = 7960$ g

b) $\bar{M} = \sum y_i M_i$

$$= (0.10)(46) + (0.75)(88) + (0.15)(60)$$

$$= 79.6 \text{ g/mol}$$

c) $m_{total} = \bar{M} * n_{total}$

1 طريقة

$$= \frac{m_i}{x_i}$$

$$n_{total} = \frac{n_2}{y_2} = \frac{25}{0.75} = 33.3 \text{ kmol}$$

$$m_{total} = (79.6)(33.3) = 2653 \text{ kg}$$

method2 ⇝ $m_2 = n_2 * M_2$

$$= 25 * 88 = 2200 \text{ kg}$$

$$m_{total} = \frac{2200}{0.83} = \frac{m_2}{x_2} \Rightarrow 2653 \text{ kg}$$

* Concentration ⇝

$$\text{mass Concentration} = \frac{\text{mass of component}}{\text{Volume of mixture}}$$

$$[=] \frac{Kg}{in^3}, \frac{g}{Cm^3}, \frac{lbm}{Ft^3}, \frac{[M]}{[L^3]}$$

$$\text{molar Conc.} = \frac{\text{\# of moles of a component}}{\text{Volume of mixture}}$$

$$[=] \frac{Kmol}{m^3}, \frac{lb\text{-}mol}{m^3}, \frac{lb\text{-}mol}{Ft^3}, \ldots$$

molarity = molar conc in mol/L

solute solution

2molar A = 2mol A/ L soln

* parts per million (ppm), parts per billion (ppb) used to express the conc of "trace species" in mixture of gases or liquids

mass ratio ⟶ liquid

mole ratio ⟶ gas

* $p.p.m = \dfrac{\text{Parts of species (g, mol)}}{10^6 \text{ parts of mixture (g, mol)}} = \begin{matrix} y_i * 10^6 \\ x_i * 10^6 \end{matrix}$

* $p.p.b = \dfrac{\text{parts of species (g, mol)}}{10^9 \text{ parts of mixture (g, mol)}} = \begin{matrix} y_i * 10^9 \\ x_i * 10^9 \end{matrix}$

TY - Pg 54 ⟶

Liquid - mostly water - contain 125 ppb phenol (mass ratio)

1. mass Fraction = ?

$x = ppb * 10^{-9}$

$= 125 * 10^{-9}$

2. How many mg phenol in 1 kg Liquid ?

$$\frac{125 * 10^{-9} \text{ g phenol}}{\text{g liquid}} \left| \frac{10^3 \text{ mg}}{\text{g}} \right| \frac{10^3 \text{ g}}{\text{kg}}$$

$= 125 * 10^{-3}$ mg phenol / kg liquid

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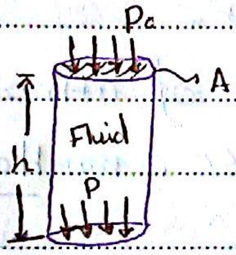
3. C_{ph} (g/L) = ?

assuming $\rho \approx \rho_w = 1 g/cm^3$

$$C_{ph} = \frac{125 * 10^{-9} \text{ g phenol}}{\text{g soln}} \left| \frac{1g}{cm^3} \right| \frac{10^3 cm^3}{1L} = 125 * 10^{-6} \text{ phenol}/L$$

* Pressure ~

$$P = \frac{F}{A} [=] \underbrace{\frac{N}{m^2}}_{Pa}, \underbrace{\frac{lbf}{in^2}}_{psi}, \frac{dyne}{cm^2}$$



$$F = F_o + W$$

$$PA = P_oA + \rho A h g$$

$$\boxed{P = P_o + \rho g h}$$

hydro static pressure — atmospheric pressure

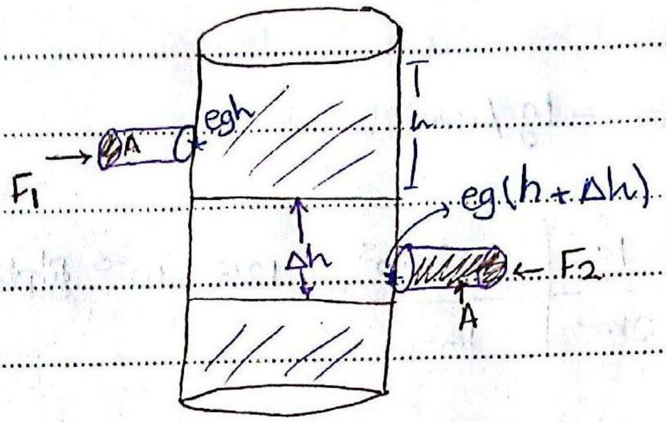
, If $P_o = 0$, $P = \rho g h$

$= \rho g P_h$ → head pressure

Example ~ Express $2*10^5$ Pa in terms of mmHg

$$P_h = \frac{2*10^5}{\rho g} = \frac{2*10^5 \overset{kg\frac{m}{s^2}}{N}}{\cancel{m^2}} \left| \frac{\cancel{m^3}}{\underbrace{13600}_{\rho_{Hg}} \cancel{kg}} \right| \frac{s^2}{9.8 \cancel{m}} = 1.5 \text{ mHg}$$

$= 1500$ mmHg



$F_2 > F_1$

$\Rightarrow P_2 > P_1$

$(A_2 = A_1)$

* Atomeshperic pressure ~~is~~

pressure at the base of column of air located at measurment point.

(top of column = top of atmosphere)

* at sea level P_{atm} = 1atm = 760.0 mmHg

1)* Absolute pressure $\Longleftrightarrow$ pressure of zero corresponds to perfect vacum.

2)* Gauge pressure = pressure relative to atmospheric pressure

* $P_{abs} = P_g + P_{atm}$

$P_{abs} \downarrow$ psia, $P_g \downarrow$ psig

* P_g can be -ve

if P_{abs} = 75.0 cmHg , P_{atm} = 76.0 cmHg

P_g = 75.0 - 76.0 = -1 cmHg

Subject:......................

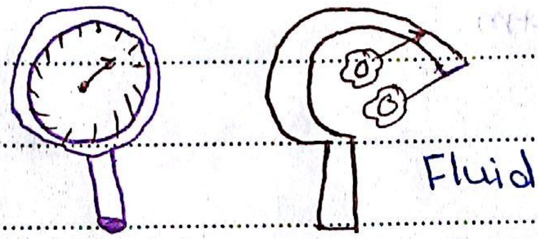
* Fluid Pressure Measurment :-

pressure Measurment devices :-

1) * Elastic - Element method

Bourden tubes

the most common

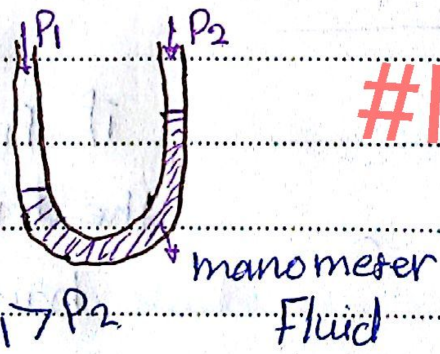


* Measures the gauge pressure

From perfect vacum to 7000 atm

- Below 3atm, manometer gives more accurate measurement

2) liquid - Column methods : manometer



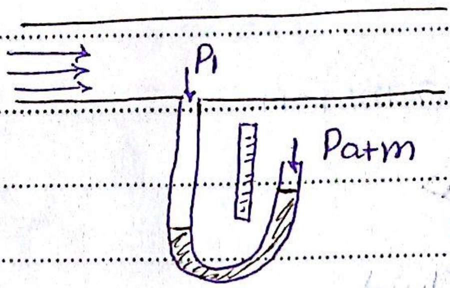
3) Electrical Methods :

Strain gauge.

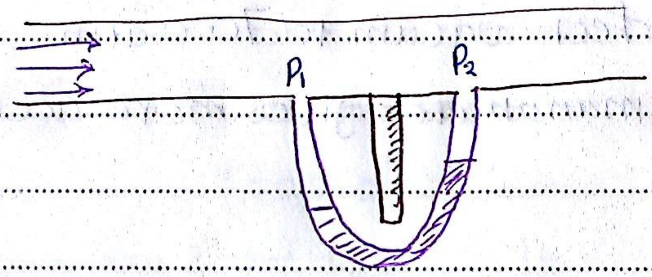
*

* Three types of Manometers:

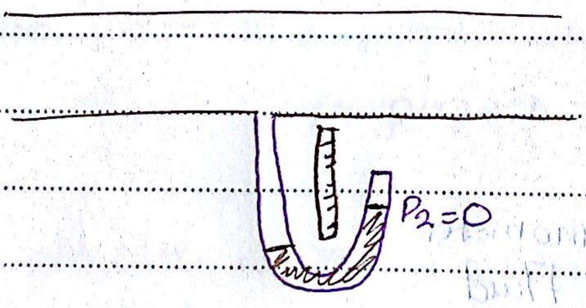
1- Open - end manometer.



2- Diffrential Manometer.

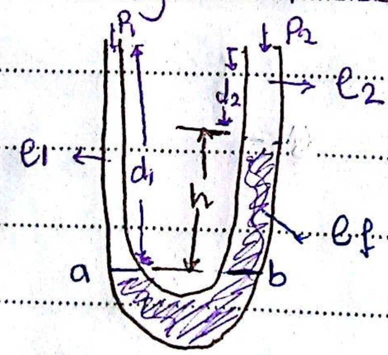


3- Sealed - end manometer.



if $P_1 = P_{atm}$ the device is called barometer.

* Reading the Pressure from the Manometer.



$P_a = P_b$ (Continuous Fluid at the same level)

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$P_a = P_b$

$P_1 + \rho_1 g d_1 = P_2 + \rho_2 g d_2 + \rho_f g h$, $\boxed{h = d_1 - d_2}$

1) * Differential manometer

$\rho_1 = \rho_2 = \rho_3$

$P_1 - P_2 = (\rho_f - \rho) g h$

2) * If Fluid (1) and Fluid (2) are gases.

$\rho_1 \ll \rho_f$, $\rho_2 \ll \rho_f$

$\boxed{P_1 - P_2 = \rho_f g h}$

3) * IF P_1 and P_2 are head pressure

$\boxed{P_1 - P_2 = h}$

* Temperature :-

a measure of the average kinetic energy possesed by a substance molecules.

* Temp is determined indirectly by measuring :
(device name)

1- electrical resistance a conductor (resistance thermometer)

2- Voltage at the conjunction of two dissimilar metals (thermocouple)

3- Specta of emitted radiation (pyremeter)

4- volume of fixed mass of fluid (thermometer)

- Temp Scales:

1) Celsius (centigrade) scale : T_f (water at 1atm) $= 0°C$

T_b (water at 1atm) $= 100°C$

Absolute zero $= -273.15°C$

2) Fehrenhiet Scale : $T_f = 32°F$, $T_b = 212°F$] absolute Zero $= -459.67°F$

3) Kelvin = Celsius + 273.15] absolute temp

* absolute zero = 0

4) Rankine = Fehrenhiet + 459.67

absoulte zero = 0

* $T(K) = T(°C) + 273.15$

$T(°R) = T(°F) + 459.67$

$T(°R) = 1.8\,T(K)$

$T(°F) = 1.8\,T(°C) + 32$

$\Delta T(°C) = \dfrac{\Delta T(°F)}{1.8}$

$\Delta T = 10$
0 — 10 °C

$\Delta T(K) = \dfrac{\Delta T(°R)}{1.8}$

$\Delta T = 18$
32 — 50 °F

$\Delta T(K) = \Delta T(^\circ C)$

$\Delta T(^\circ R) = \Delta T(^\circ F)$

P3.48 ⇝ a) $T = 85^\circ F$ to $^\circ R$, $^\circ C$, K

$T(^\circ R) = 85 + 460 = 545^\circ R$

$T(^\circ C) = \dfrac{85 - 32}{1.8} = 29.4^\circ C$

$T(K) = 29.4 + 273.15 = 302.55\, K$

C) $\Delta T = 85^\circ C$, to K, $^\circ F$, $^\circ R$

$\Delta T(K) = 85\, K$

$\Delta T(^\circ F) = 1.8(85) + 32 = 185^\circ F$

$\Delta T(^\circ R) = 185 + 459.67$

$= 644.67^\circ R$

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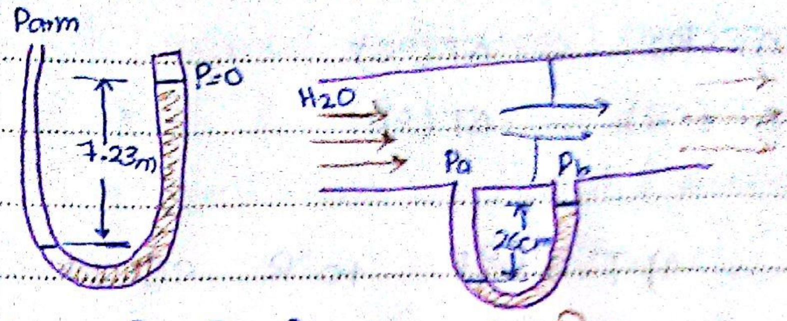
Subject: ....

manometer Fluid of Unknown density

$P_{atm} = 756\,mmHg$

P3-43 ⇝



What is $\Delta P = P_a - P_b$ in mmHg ?

Sol ⇝ $\Delta P = (\rho_f - \underset{\text{water}}{\rho})\, g\, h$

For the barometer ⇝

$\Delta P = (\rho_f - \underbrace{\rho_{air}}_{=0})\, g h$

$P_{atm} - 0 = (\rho_f)\, g\, (7.23m)$

$$\frac{756\ mmHg}{} \left| \frac{101325\ N}{m^2} \right| \frac{}{760\ mmHg}$$

$$= \rho_f \frac{kg}{m^3} \left| \frac{9.8m}{s^2} \right| 7.23m \left| \frac{N \cdot s^2}{kg \cdot m} \right.$$

$\rho_f = 1420\ Kg/m^3$

$\Delta P_{a \to b} = (1420 - 1000)(9.8)(0.26m)$

$= 8.0\ mmHg$