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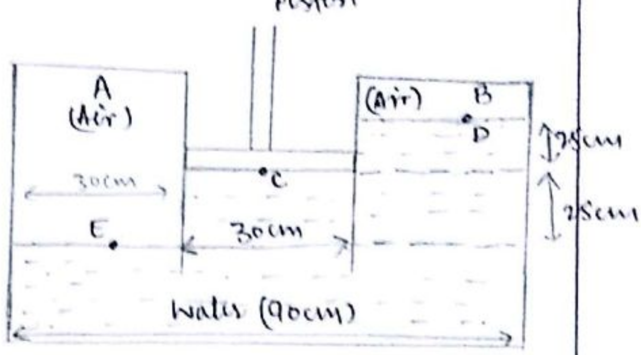
ENGINEERING THERMODYNAMICS ASSIGNMENT

Q1. Two chambers with same fluid at their base are separated by a piston whose weight is 25N, as shown. Calculate the gauge pressures in chambers A and B.

Solution. Density of water = 1000 kg/m³



$$P_C = P_{atm} + \frac{W_{piston}}{A_{piston}}$$

By using hydrostatic pressure relation,

$$P_A = P_E = P_C + \rho_w g(\overline{CE}) = P_{atm} + \frac{W}{A} + \rho g(\overline{CE})$$

$$\Rightarrow P_A - P_{atm} = P_{A(gauge)}$$

$$= \frac{W}{A}(\text{piston}) + \rho g(\overline{CE})$$

$$= \frac{25\ N}{\pi\left(\frac{0.3}{2}m\right)^2} + (1000\,kg/m^3)(9.81\,m/s^2)(0.25\,m)\left(\frac{1N}{1kg\cdot m/s^2}\right) = 2806\,N/m^2 = 2.806\ KPa$$

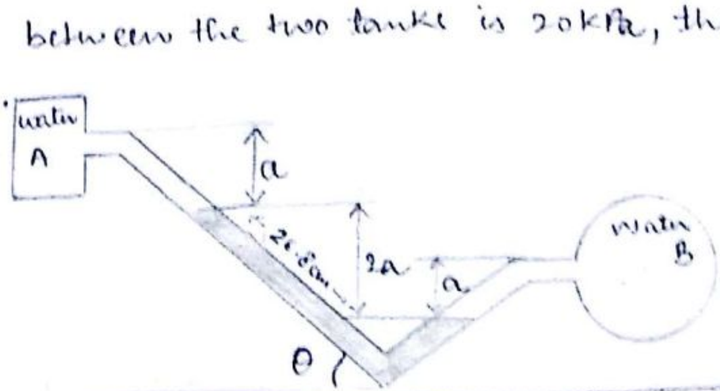
Similarly,

$$P_B = P_D = P_C - \rho g(\overline{CD}) = P_{atm} + \frac{W_{piston}}{A_{piston}} - \rho g(\overline{CD}) \Rightarrow P_B - P_{atm} = P_{B(gauge)}$$

$$P_{B(gauge)} = \frac{25\ N}{\pi\left(\frac{0.3}{2}m\right)^2} - (1000\,kg/m^3)(9.8\,m/s^2)(0.25\,m)\left(\frac{1N}{1kg\,m/s^2}\right) = -2099\,N/m^2$$
$$= -2.099\ KPa$$

Ans: The gauge pressures in A and B are 2.806 KPa and -2.099 KPa respectively.

Q2. Two water tanks are connected to each other through a mercury manometer with inclined tubes as shown. If the pressure difference between the two tanks is 20 KPa, then calculate α and θ.



(Mercury SG = 13.6)

Solution. $\rho_w = 1000\ kg/m^3$ $\because SG_{mercury} = 13.6 \Rightarrow \rho_m = 13600\ kg/m^3$

Starting from tank A and moving along the tube by adding or subtracting the $\rho g h$ terms until we reach tank B and setting result equal to P_B gives;

$$\therefore\ P_A + \rho_w g a + \rho_m g (2a) - \rho_w g a = P_B$$

$$\Rightarrow \quad 2\rho_m g a = P_B - P_A \quad \text{also} \ (P_B - P_A = 20\ kPa)$$

$$\Rightarrow \quad a = \frac{P_B - P_A}{2\rho_m g a} = \frac{20\ kN/m^2}{2(13.6)(1000\ kg/m^3)(9.81\ m/s^2)}\left(\frac{1000\ kg \cdot m/s^2}{1\ kN}\right)$$

$$= 0.0750\ m$$

$$\boxed{a = 7.50\ cm.}$$

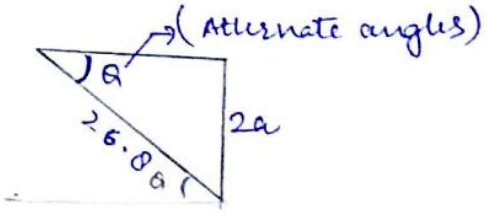
from geometric considerations

$$2a \sin\theta = 26.8$$

$$2 \times 7.50 \sin\theta = 26.8$$

$$\sin\theta = 0.560$$

$$\boxed{\theta = 34^\circ}$$



Ans: $a = 7.50\ cm$ and $\theta = 34^\circ$.

Q3. Calculate the pressure generated by an ordinary shoe heel (person of mass 40 kg, heel 5cm x 5cm), an elephant (of mass 500 kg, foot of 20cm diameter) and a high heeled shoe (person of mass 40kg heel of area 0.5 cm²). Which one will damage a wooden floor that starts to yeild at a pressure of 4000 kPa?

Solution. Pressure exerted by 1st person $(P_1) = \frac{40\ kg \times 9.8}{0.05 \times 0.05} = 156800\ Pa$

Pressure exerted by elephant $(P_e) = \frac{500 \times 9.8}{\pi \times 0.1 \times 0.1} = 156050\ Pa$

Pressure exerted by 2nd person $(P_2) = \frac{40 \times 9.8}{0.5 \times 10^{-4}} = 7840000\ Pa$

P_y = yielding pressure = 4000 kPa

Acc. to our solution

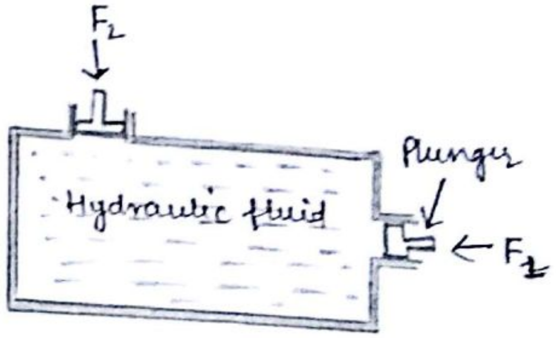
$P_1 = 156.8$ kPa $\quad P_e = 156.05$ kPa $\quad P_2 = 7840$ kPa

$\Rightarrow \quad P_2 > P_y \quad \because (7840 > 4000)$

Ans $\Rightarrow$ Person 2 will damage the wooden floor.

Q4. The basic elements of a hydraulic press are shown. The plunger has an area of $3\,cm^2$ and a force F_1 can be applied, to plunger through a lever mechanism having a mechanical advantage of 8 to 1. If the large piston has an area of $150\,cm^2$, what load, f_2 can be raised by a force of 30N applied to the lever?

Solution.



According to question,

mechanical advantage = 8:1

$$\Rightarrow \quad \frac{F_1}{F} = \frac{8}{1}$$

$$F_1 = 8F$$

also given $f = 30N$, $A_1 = 3\times10^{-4} m^2$, $A_2 = 150\,cm^2 = 150\times10^{-4} m^2$

Applying Pascal's law,

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

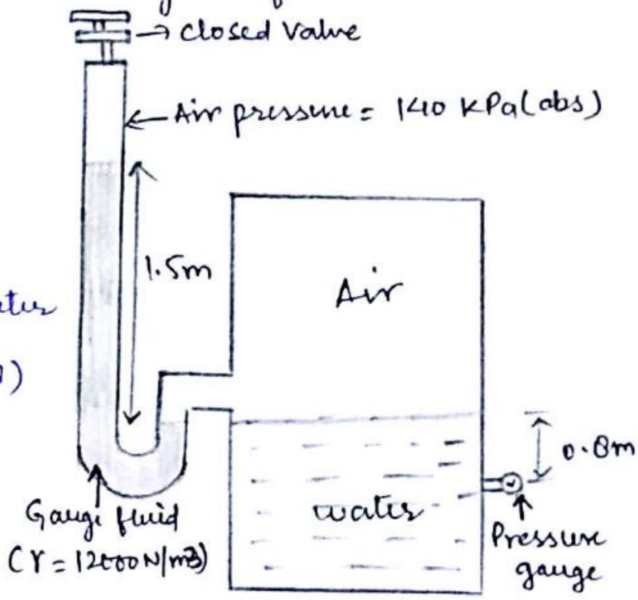
$$\Rightarrow \quad \frac{8F}{F_2} = \frac{\cancel{3}\times\cancel{10^{-4}}}{\underset{50}{\cancel{150}}\times\cancel{10^{-4}}} \Rightarrow F_2 = 400\times F$$

$$F_2 = 400\times 30\,N$$

$$= 12000\,N$$

Ans = $\boxed{F_2 = 12\,KN}$

Q5. A tube manometer is connected to a closed tank containing air and water as shown. At the closed end of manometer the absolute air pressure is 140 KPa. Determine the reading on the pressure gauge for a differential reading of 1.5 m on the manometer. Express your answer in gauge pressure value. Assume standard atmospheric pressure and neglect the weight of the air columns in the manometer.



Solution. $P_{air} = 140 \, KPa$

$P_{fluid} = 1.5 \times 12000 \, N/m^2$

$\Rightarrow$ total pressure exerted by manometer

$\Rightarrow 140 \, KPa + 1.5 \times 12000 \, N/m^2 + \rho_w g (0.8)$

$= 140000 + 18000 + 1000 \times 0.8 \times 9.8$

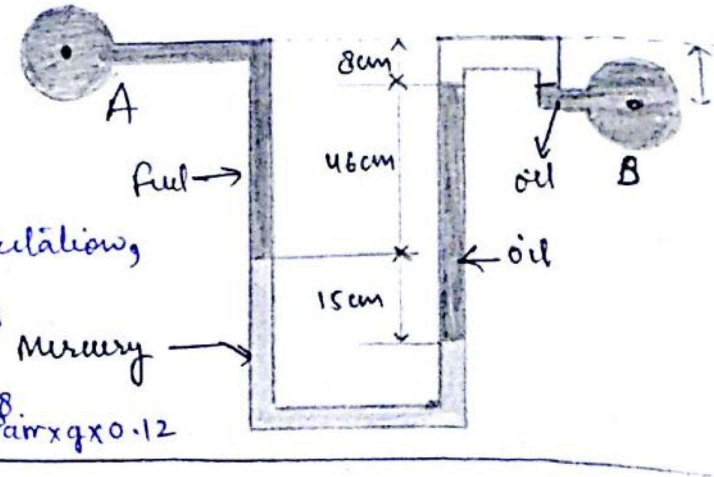
$= 158000 + 7840$

$= 165840 = P_{total}$

$P_{gauge} = P_{total} - P_{atm} \Rightarrow 165840 - 100000 = 65840 \, Pa$

Ans. $\boxed{P_{gauge} = 65.8 \, KPa}$

Q.6. A mercury manometer is used to measure the pressure diff. in the two pipelines as shown. Fuel ($\rho_f = 850 \, kg/m^3$) is flowing in A and oil ($\rho_o = 915 \, Kg/m^3$) is flowing in B. An air pocket has become entrapped in the oil as indicated. Determine the pressure in pipe B if the pressure in A is 105.5 KPa.



Solution. Given $P_A = 105.5 \, KPa$

also. $\rho_f = 850 \, kg/m^3$,

$\rho_o = 915 \, kg/m^3$.

applying hydrostatic pressure relation,

$$P_A + \frac{54}{100} \times \rho_f \times g + \frac{15}{100} \times \rho_{Hg} = \frac{61}{100} \times \rho_o \times g + P_B - \rho_{air} \times g \times 0.8 + \rho_{air} \times g \times 0.12$$

$\Rightarrow$ 105500 + 4498.2 + 19992 = 5469.87 + P_B + 1.38

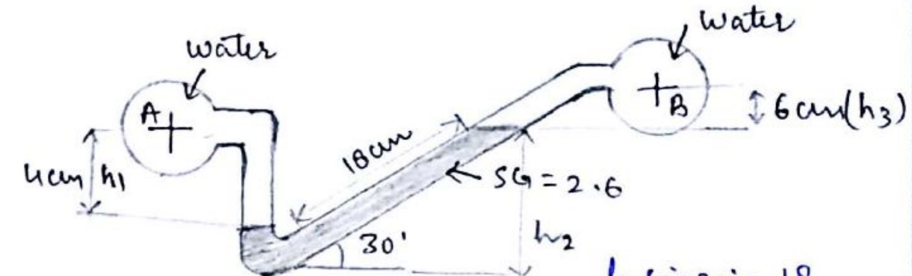
taking constants one side,

P_B = 124908 Pa

i.e P_B = 124.908 KPa

Ans: pressure in pipe B = $\boxed{P_B = 124.9 \text{ KPa}}$

Q.7 For the inclined Tube manometer, the pressure in pipe A is 8 KPa. The fluid in both pipes A and B is water, and the gauge fluid in the manometer has a specific gravity of 2.6. What is the pressure in pipe B corresponding to the differential reading shown?



$h_2 \sin 30° = 18$

h_2 = 9 cm

Solution.

Simply applying hydrostatic pressure relation, we get,

$P_A + \rho_w \times g \times h_1 = \rho_e \times g \times h_2 + \rho_w \times g \times h_3 + P_B$

$\Rightarrow P_A + 0.04 \times 9.8 \times 1000 = 0.09 \times 2600 \times 9.8 + 0.06 \times 1000 \times 9.8 + P_B$

$\Rightarrow$ P_A 8000 + 392 = 2881.2 + P_B

P_B = 8000 + 392 − 2881.2

P_B = 5510.8 Pa

P_B = 5.510 KPa

Ans $\Rightarrow$ $\boxed{P_B = 5.510 \text{ KPa}}$

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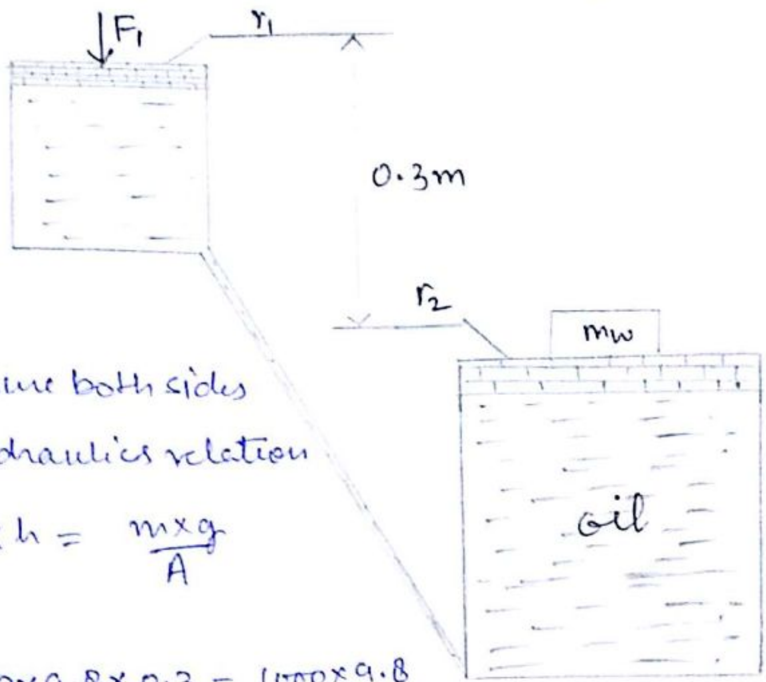
Q.8. A weight lies on a piston with a radius $r_2 = 1.0m$. Determine the force applied (F_1) to the piston with radius $r_1 = 20cm$ if the hydraulic jacks is in balance. The jack is filled by an oil with $\rho_o = 850\ kg/m^3$. Mass of weight is $m_w = 1000\ kg$. Neglect the mass of pistons.



Solution.

Equating pressure both sides by using hydraulics relation

$$\frac{F_1}{A_1} + \rho_{oil} \times g \times h = \frac{m \times g}{A}$$

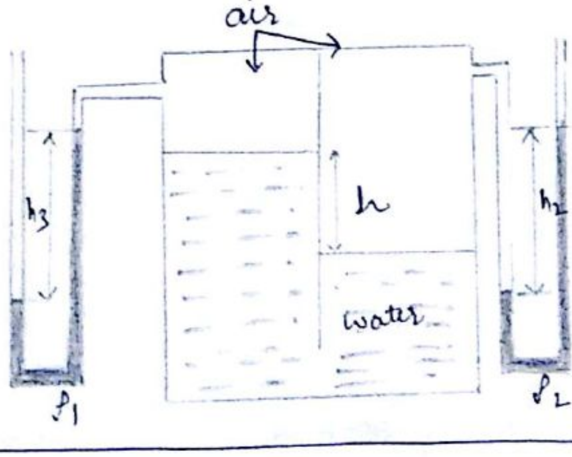
$$\frac{F_1}{\pi \times 0.2 \times 0.2} + 850 \times 9.8 \times 0.3 = \frac{1000 \times 9.8}{\pi \times 1 \times 1}$$

$$\Rightarrow \frac{F_1}{\pi \times 0.04} + 2499 = 3119.43$$

$$F_1 = \pi \times 0.04\,(3119.43 - 2499)$$

Ans = $\boxed{F = 77.96N}$

Q9. Calculate a formula for manometer reading h_2 for a situation shows at figure. As a known values we have: $h_3, h, \rho_1, \rho_2, \rho_w$.



Solution.

Again using hydraulics relation,

$$P_{atm} - \rho_1 g h_3 + \rho_w g h = \rho_2 g h_2 + P_{atm}$$

$$\rho_w g h - \rho_1 g h_3 = \rho_2 g h_2$$

$$\Rightarrow \frac{\rho_w g h - \rho_1 g h_3}{\rho_2 g} = h_2$$

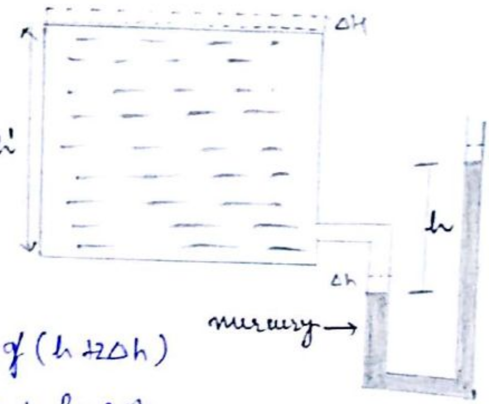
Ans. $\Rightarrow$ $$\boxed{h_2 = \frac{\rho_w h - \rho_1 h_3}{\rho_2}}$$

Q.10. A mercury manometer is connected to open tank of fuel. Calculate a change of manometer reading h if a level of fuel increases about ΔH.

Solution

Initial Equilibrium,

$$P_{atm} + \rho_f g h' = \rho_{Hg} g h + P_{atm}$$



$$\rho_f h' = \rho_{Hg} h \quad -(1)$$

Finally,

$$\rho_f g (h' + \Delta H + \Delta h) = \rho_{Hg} g (h + 2\Delta h)$$

$$\rho_f h' + \rho_f \Delta H + \rho_f \Delta h = \rho_{Hg} h + \rho_{Hg} 2\Delta h$$

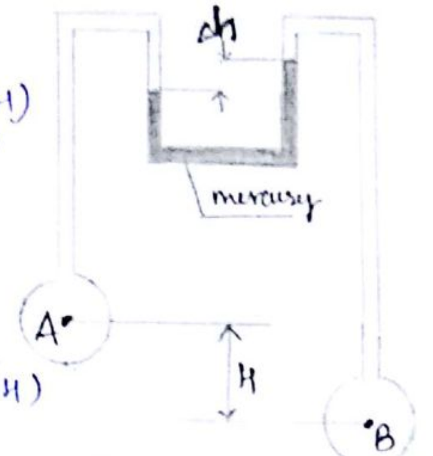
$$\cancel{\rho_{Hg} h} + \rho_f \Delta H + \rho_f \Delta h = \cancel{\rho_{Hg} h} + \rho_{Hg} 2\Delta h \quad \text{(using (1))}$$

$$\rho_f \Delta H = (2\rho_{Hg} - \rho_f)\Delta h$$

Ans = $$\boxed{\Delta h = \frac{\rho_f \Delta H}{2\rho_{Hg} - \rho_f}}$$

Q11. A mercury manometer connects two oil pipelines. Calculate a pressure difference between points A and B if $H = 2m$, $\Delta h = 0.2m$, $\rho_o = 800\ kg/m^3$, $\rho_m = 13600\ kg/m^3$.

Solution.



$$P_A - \rho_{oil} g h_1 - \rho_{Hg} g \Delta h + \rho_{oil} g (h_1 + H + \Delta h) = P_B$$

$$\Rightarrow P_A - \rho_{Hg} g \Delta h + \rho_{oil} g (\Delta h + H) = P_B$$

$$\Rightarrow P_A - P_B = \rho_{Hg} g \Delta h - \rho_{oil} g (\Delta h + H)$$

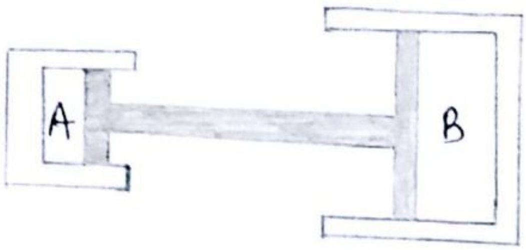
$$= 13600 \times 9.8 \times 0.2 - 800 \times 9.8 \times 2.2$$

$$\boxed{P_A - P_B = 9418\ Pa}$$

Ans: $P_A - P_B = 9418\,Pa$ or $9.418\,KPa$

Q.12. If $P_A = P_B$, in which direction the piston will move. Explain using equations.

Solution:



Given that,

$$P_A = P_B$$

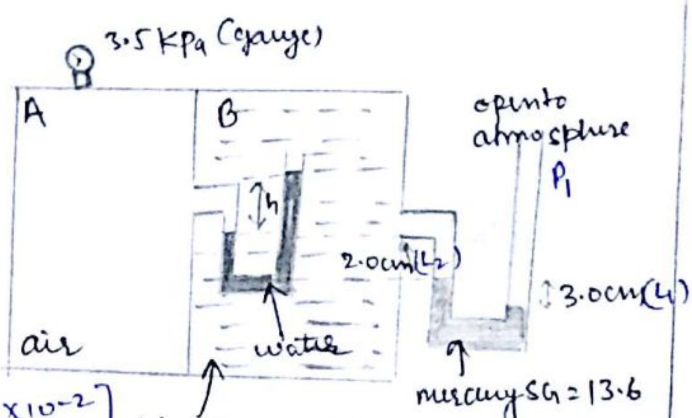
and $P = \frac{F}{A} \Rightarrow \frac{F_A}{A_A} = \frac{F_B}{A_B}$

$$\frac{F_A}{F_B} = \frac{A_A}{A_B} \Rightarrow F_B = F_A\left(\frac{A_B}{A_A}\right) \text{ -(1)}$$

$\because A_B > A_A \Rightarrow \frac{A_B}{A_A} > 1$ and $\Rightarrow \boxed{F_B > F_A}$

Since force due to B is more than force due to A, thats why piston will move towards A.

Q13. Compartments A and B of the tank shown in the figure below are closed and filled with air and a liquid with a specific gravity equal to 0.6. If atmospheric pressure is 101 KPa and pressure gauge reads 35 KPa (gauge) determine the manometer reading.



Solution. $P_2 = P_1 - \rho_{Hg} g l_1$

$P_3 = P_2 - \rho_l g (h + l_2)$

$P_4 = P_3 + \rho_w g h$

$P_4 = P_1 - \rho_{Hg} g l_1 - \rho_l g (h + l_2) + \rho_w g h$

$P_4 - P_1 = -\rho_w g (SG_{Hg} l_1 + SG_l h + SG_l l_2 - h)$

$$h = \frac{-1}{(1-0.6)}\left[\frac{(0-3.5)10^3}{1000 \times 9.81} - 13.6 \times 3 \times 10^{-2} - 0.6 \times 2 \times 10^{-2}\right]$$

$$h = \frac{-1}{0.4}\left[-0.356 - 0.408 - 0.012\right]$$

Ans = $\boxed{h = 1.94 \text{ metres}}$

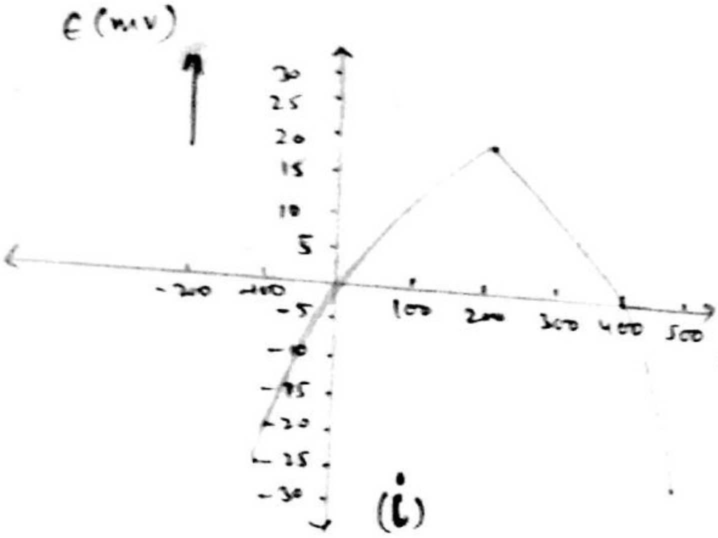
Q.14 When a reference junction of thermocouple is kept at the ice point and the test junction is at Celsius temperature T, and emf ϵ of the thermocouple is given by $\epsilon = aT + bT^2$; where $a = 0.20\, mV/^\circ C$ and $b = -5.0 \times 10^{-4}\, mV/^\circ C^2$.

a) Compute the emf when T = $-100^\circ C$, $200^\circ C$, $400^\circ C$, $500^\circ C$ and plot the graph of ϵ against T in this range.

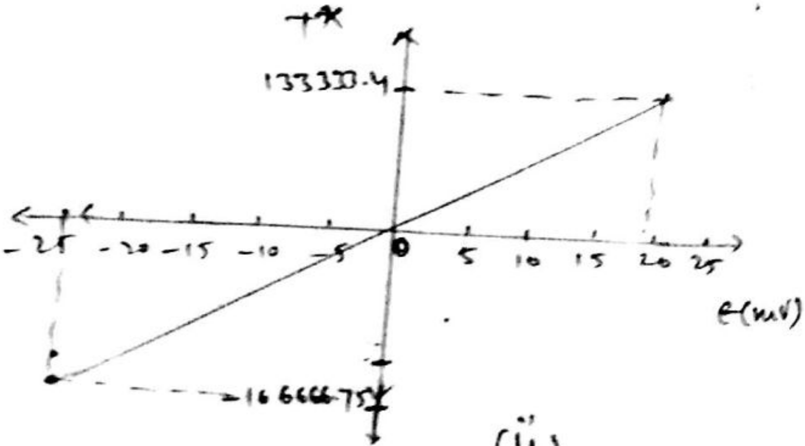
b) Suppose emf is taken as a thermometric property and that a temp. scale T^* is defined by the linear relation $T^* = a'\epsilon + b'$; and that $T^* = 0$ at the ice point and $T^* = 100$ at steam point. Find the numerical value a' & b' and draw a graph b/w ϵ & T^*.

c) Find the value of T^*, when T = $-100^\circ C$, $200^\circ C$, $400^\circ C$, and $500^\circ C$ and plot the graph of T^* against T.

d) Compare the celsius scale with T^* scale.


e (mV)
30
25
20
15
10
5
-5
-10
-15
-20
-25
-30
-200
-100
100
200
300
400
500
T

(i)


T*
133333.4
-25
-20
-15
-10
-5
0
5
10
15
20
25
e(mV)
-166666.75

(ii)


T*
1333334
-100
100
200
300
400
500
T
-166666.75

Solution. $\epsilon = aT + bT^2$

a) given $a = 0.2\times10^{-3}\ V/^\circ C$ $b = -5\times10^{-7}\ V/^\circ C^2$

(i) $\epsilon_{-100} = -0.2\times10^{-3}\times10^{2} - 5\times10^{-7+4} = -0.025\ V = -25\ mV$

(ii) $\epsilon_{200} = 0.2\times10^{-3}\times200 - 5\times10^{-7+4}\times4 = 0.02\ V = 20\ mV$

(iii) $\epsilon_{400} = 0.2\times10^{-3}\times400 - 5\times10^{-7+4}\times16 = 0\ mV$

(iv) $\epsilon_{500} = 0.2\times10^{-3}\times500 - 5\times10^{-7}\times25\times10^{4} = -0.025 = -25\ mV$.

b) $T^* = a'\epsilon + b'$

$T^* = 0$ at $T = 0 \Rightarrow T^* = a'(aT + bT^2) + b' = 0$

$b' = 0$

$T^* = 100 = a'(-15\mu V) \Rightarrow a' = \cancel{67}\ -6666.67 \Rightarrow T^* = a'\epsilon$

$T^*_{-25} = \cancel{1675}\ -166666.75$ at $\epsilon = -25\ mV$

$T^*_{20} = \cancel{134}\ 133333.4$ at $\epsilon = +20\ mV$

$T^*_{0} = 0$ at $\epsilon = 0\ mV$

c) T^* vs T

$\Rightarrow T^*$ at $-100^\circ C = (\epsilon = -25 mV) \Rightarrow T^*_{-25} = -166666.75$

T^* at $200^\circ C = T^*_{20mV} = 133333.4$

T^* at $400^\circ C = T^*_{0} = 0$

T^* at $500^\circ C = T^*_{-25} = -166666.75$

15. A platinum wire is used as resistance thermometer. The wire resistance was found to be 10Ω and 16 Ω at icepoint and steam point respectively, and 30Ω at sulphur boiling point of 444.6°C. find the resistance of the wire at 500°C, if the resistance varies with temperature by the relation:

$$R = R_0(1 + \alpha T + \beta T^2)$$

Solution

$$R_0 = 10\,\Omega$$

$$R_{100} = R_0(1 + \alpha(100) + \beta(100)^2)$$

or $$16 = 10(1 + \alpha(100) + \beta(100)^2)$$

$$0.6 = 100\alpha + 10000\beta$$

$$6\times10^{-3} = \alpha + 100\beta \quad \text{—(i)}$$

also $$30 = 10(1 + \alpha(444.6) + \beta(444.6)^2)$$

$$\frac{2}{444.6} = \alpha + 444.6\beta$$

$$4.49\times10^{-3} = \alpha + 444.6\beta \quad \text{—(ii)}$$

Subtracting (i) from (ii) we get.

$$-1.51\times10^{-3} = 344.6\beta$$

$$\beta = -4.38\times10^{-6}$$

$$\alpha = 6.43\times10^{-3}$$

$$R_{500} \Rightarrow R_0(1 + \alpha(500) + \beta(500)^2)$$

$$= 10(1 + (6.43\times10^{-3}\times500) + (-4.38\times10^{-6}\times250000)$$

$$= 10(1 + 3.215 + (-1.095))$$

$$= 10(3.12)$$

$$\boxed{R_{500} = 31.2\,\Omega}$$

Ans = R at 500°C is 31.2 Ω