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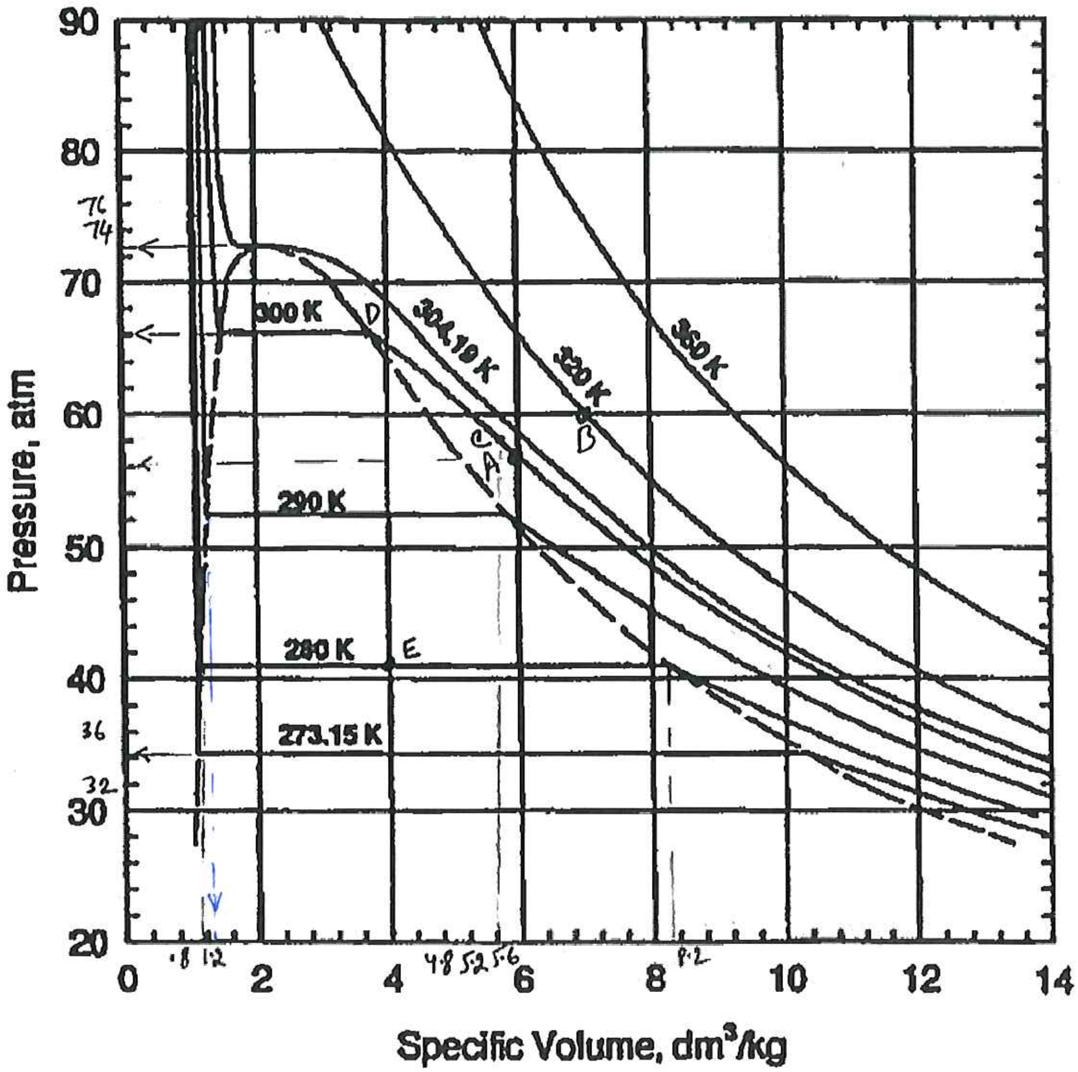
3. Use the phase diagram for the vapour-liquid region of CO_2 to answer the following questions. Show all your work for full marks.



Pressure - Volume Diagram for CO_2

(a) (i) What is the critical pressure of CO_2. (2)

$P_{cr} \simeq \boxed{72.5 \text{ atm}}$

(ii) Estimate the vapor pressure of CO_2 at 0°C.(/2)

$0°C = 298.15K$

$P_{vap} \simeq \boxed{34.1 \text{ atm}}$

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(iii) What phase or phases exist at 300 K and at a specific volume of 6 dm³/kg? (/2)

$T = 300K < T_c$

Point A: $P < P_c$, state is $\boxed{\text{VAPOUR}}$

(iv) What phase or phases exist at 320 K and at 60 atm? (/2)

Point B: $T = 320K > T_c$

$P < P_c$

state is $\boxed{\text{GAS}}$

(v) Is the pressure of the system at the following conditions (T = 300K, specific volume = 6 dm³/kg) greater or less or equal to the vapor pressure of CO_2 at 300 K (/3)

@ $T = 300K$, $\hat{V} = 6\ dm^3/kg$ $\rightarrow$ point A.

$P_{system} \simeq 56$ atm

$P_{vap@300K} \simeq 66$ atm

$\boxed{P_{system} < P_{vap}}$

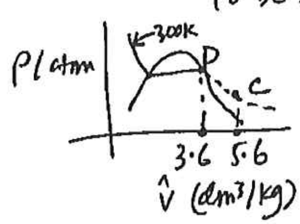
(vi) 100 kg of pure CO_2 is contained in a rigid container of volume 560 dm³ at a temperature of 300K. Determine how much CO_2 (kg) would have to be added to the container at the same temperature so that the phase of CO_2 become saturated vapor? (/4)

100 kg CO_2 in $560 dm^3$ $\Rightarrow \hat{V} = \frac{560}{100} = 5.6\ \frac{dm^3}{kg}$ @ $T = 300K$

point C.

To be saturated, $\hat{V}$ should be $\simeq 3.6\ \frac{dm^3}{kg}$

(point D)



Then, $\frac{560}{m_{new}} = 3.6$

$\Rightarrow m = 155.6$ kg

Then $(155.6 - 100) = \boxed{55.6\ kg}$ CO_2 should be added.

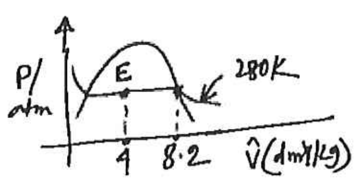
(b) A separate container of volume 400 dm³ contains 100 kg of CO_2 at a temperature of 280K.

$\left.\begin{array}{l}\hat{V} = 4\ dm^3/kg \\ T = 280\ K\end{array}\right\} \Rightarrow$ (L+V) at point E

(i) What is the specific volume of the vapor present inside the container? (/2)

$\hat{V}_{mixture} = 4\ dm^3/kg$

$\hat{V}_{vapor} = \boxed{8.2\ dm^3/kg}$



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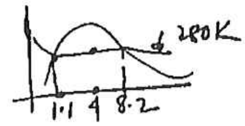
(ii) What is the specific volume of the liquid present inside the container? (/2)

$$\hat{V}_{liq} \simeq 1.1 \ \frac{dm^3}{kg}$$



(iii) How much liquid is present? (/4)

Liq ———— mix ———— Vapor

$$\frac{m_L}{m_{tot}} = \frac{\hat{V}_{vap} - \hat{V}_{mix}}{\hat{V}_{vap} - \hat{V}_{liq}} = \frac{8.2-4}{8.2-1.1} \simeq 0.59$$

$$\Rightarrow \quad m_L = 0.59 \times m_{tot} = 0.59 \times 100 \text{ kg} = \boxed{59 \text{ kg}}$$

Both are OK.

or, in terms of volume, $V_{liq} = (59 \text{ kg})(1.1 \frac{dm^3}{kg}) = \boxed{65 \ dm^3}$

(iv) The temperature of the above container is raised to 290 K. What fraction of total mass is liquid? (/5)

Rise in temp changes the specific volumes of vap & liq.

$\hat{V}_{liq} \simeq 1.2$ ———— $\hat{V}_{mix} = 4$ ———— $\hat{V}_{vap} \simeq 5.8$

$$\frac{m_{liq}}{m_{tot}} = \frac{\hat{V}_{vap} - \hat{V}_{mix}}{\hat{V}_{vap} - \hat{V}_{liq}} = \frac{5.8-4}{5.8-1.2} = \boxed{0.39} \quad \text{Ans}$$

$$\Rightarrow \cancel{m_{liq} = \boxed{37.5 \text{ kg}}}$$

(v) Calculate the degree of freedom for the system when the temperature of the container is raised to 290 K as in part (iv). (/2)

$F = 2 + C - P$

From part (iv) $P = 2$

$F = 2 + 1 - 2 = \boxed{1}$ Ans

Note: Since T is given, there is no intensive variable left to be specified.

$F_{available} = \boxed{0}$