ENGG 201 - WINTER 2017 – MIDTERM EXAM #1

Wednesday February 15, 2017 - 19h00-21h00 (120 minutes)

a) Attempt all **four (4)** questions – total 100 marks
b) Show all work for full marks.
c) Formula and conversions on last page
d) Closed Text, Closed Notes, Schulich Calculators (only) are allowed.
e) Print your name and lecture number below, and put your ID number on each additional page in the blanks provided.

SOLUTION

Surname ______________ Given Name(s) ______________ Section ______

L01 (330pm TR): Dr. Sumon // L02 (1230pm TR): Dr. Kallos

STUDENT IDENTIFICATION

Each candidate must sign the Seating List confirming presence at the examination. All candidates for final examinations are required to place their University of Calgary student I.D. cards on their desks for the duration of the examination. (Students writing mid-term tests can also be asked to provide identity proof.) Students without an I.D. card who can produce an acceptable alternative I.D., e.g., one with a printed name and photograph, are allowed to write the examination.

A student without acceptable I.D. will be required to complete an Identification Form. The form indicates that there is no guarantee that the examination paper will be graded if any discrepancies in identification are discovered after verification with the student's file. **A Student who refuses to produce identification or who refuses to complete and sign the Identification Form is not permitted to write the examination.**

EXAMINATION RULES

(1) Students late in arriving will not normally be admitted after one-half hour of the examination time has passed:
(2) No candidate will be permitted to leave the examination room until one-half hour has elapsed after the opening of the examination, nor during the last 15 minutes of the examination. All candidates remaining during the last 15 minutes of the examination period must remain at their desks until their papers have been collected by an invigilator.
(3) All enquiries and requests must be addressed to supervisors only.
(4) **Candidates are strictly cautioned against:**
(a) speaking to other candidates or communicating with them under any circumstances whatsoever;
(b) bringing into the examination room any textbook, notebook or memoranda not authorized by the examiner;
(c) making use of calculators and/or portable computing machines not authorized by the instructor;
(d) leaving answer papers exposed to view;
(e) attempting to read other student's examination papers.
The penalty for violation of these rules is suspension or expulsion or such other penalty as may be determined.
(5) Candidates are requested to write on both sides of the pages unless the examiner has asked that the left hand page be reserved for rough drafts or calculations.
(6) Discarded matter is to be struck out and not removed by mutilation of the examination answer book.
(7) Candidates are cautioned against writing in their answer book any matter extraneous to the actual answering of the question set.
(8) The candidate is to write his/her name on each answer book as directed and is to number each book.
(9) A candidate must report to a supervisor before leaving the examination room.
(10) Answer books must be handed to the supervisor-in-charge promptly when the signal is given. Failure to comply with this regulation will be cause for rejection of an answer paper.
(11) If during the course of an examination a student becomes ill or receives word of domestic affliction, the student should report at once to the supervisor, hand in the unfinished paper and request that it be cancelled. If physical and/or emotional ill health is the cause, the student must report at once to a physician/counselor so that subsequent application for a deferred examination is supported by a completed Physician/ Counselor Statement form. Students can consult professionals at University Health Services or University Counseling Services during normal working hours or consult their physician/counselor in the community.
Should a student write an examination, hand in the paper for marking, and later report extenuating circumstances to support a request for cancellation of the paper and for another examination, such a request will be denied.
(12) Smoking during examinations is strictly prohibited.

Question Number I *(25 Marks ~ 30 minutes)*

PART A

a) The fluid motion in the boundary layer due to the effect of buoyancy is governed by the following equation.

$$\underbrace{u\frac{\partial u}{\partial x}}_{A} + \underbrace{w\frac{\partial u}{\partial y}}_{B} = \underbrace{v\frac{\partial^2 u}{\partial y^2}}_{C} + \underbrace{g\beta(T - T_\infty)}_{D}$$

Where,

u = speed in the x-direction
w = speed in the y-direction
x = distance
y = distance
g = gravitational acceleration (m/s^2)
T= Fluid Temperature within boundary layer
T_∞= Fluid Temperature from boundary layer
v = kinematic viscosity of fluid

i. Determine the dimensions of the coefficient β. (/2)

$[A] = [D]$

$[A] = \left[u\frac{\partial u}{\partial x}\right] = \frac{[u]^2}{[x]} = [L]^2[t]^{-2}[L]^{-1} = [L]^1[t]^{-2}$

$[L]^1[t]^{-2} = [g][\beta][T]$

$\cancel{[L]^1[t]^{-2}} = \cancel{[L]^1[t]^{-2}}[\beta][T]^1$

$[\beta] = [T]^{-1}$

ii. Determine the dimensions of v. Give its typical units. (/3)

$[A] = [C] = [v]\frac{[u]}{[y^2]} = [L]^1[t]^{-2}$

$[v] = [L]^1[t]^{-2}[L]^2[L]^{-1}[t]^1$

$[v] = [L]^2[t]^{-1}$ m^2/s

b) Three quantities x, y, and z have SI units of m/s, s, m^2 respectively. Which of the following is NOT dimensionless? (Choose the best answer from the following): (/3)

i. $\frac{xy}{\sqrt{z}}$ ii. $\frac{z}{x^2y^2}$ iii. $x^2y^2 - z$ iv. None

$[x] = [L]^1[t]^{-1}$
$[y] = [t]^1$
$[z] = [L]^2$

i) $\frac{[L]^1[t]^{-1}[t]^1}{\sqrt{[L]^2}} = 1$

iii) $[L]^2\cancel{[t]^{-2}}\cancel{[t]^2}$
$= [L]^2$

ii) $\frac{[L]^2}{[L]^2[t]^{-2}[t]^2} = 1$

c) Three quantities A, B, C are related by the following dimensionally homogeneous equation:

$$\sqrt{A} = \frac{B^2}{\sqrt{A}} + \frac{AC}{B}$$

Show that the quantity C is dimensionless. (/3)

multiply by $\sqrt{A}$

$A = B^2 + \frac{A\sqrt{A}C}{B} \rightarrow [A] = \left[\frac{A\sqrt{A}C}{B}\right]$

$[A] = [B^2]$

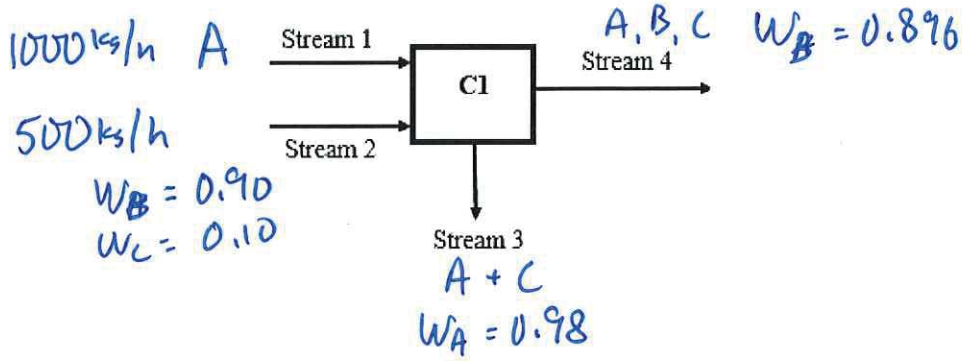
$\frac{[B]}{[\sqrt{A}]} = \boxed{[C] = 1}$

PART B

A steady-state separation process is shown in the diagram. A pure liquid stream of component A (Stream 1) and a stream of a gas mixture (Stream 2) enters into a column (C1). The flow rate of stream 1 is 1000 kg/h. The flow rate of stream 2 is 500 kg/h and it has the following composition: 90 mass percent B and 10 mass percent C. Streams 1 and 2 mix inside the column (C1). Two streams (stream 3 and stream 4) leave the column (C1).

Stream 3 contains A and C only (no B), and the mass fraction of A is 0.98. Stream 4 contains A, B, and C. The mass fraction of B in stream 4 is 0.896.

MW: A =18 kg/kmol, B= 58 kg/mol, C= 29 kg/kmol.



a) Calculate the flow rates (kg/h) of B and C in stream 2. (/2)

$\dot{m}_B = 0.90(500) = 450$ kg/h

$\dot{m}_C = 0.10(500) = 50$ kg/h

b) Calculate the flow rate (kg/h) of B in stream 4. (/2)

All of B goes to 4

$\dot{m}_B = 450$ kg/h

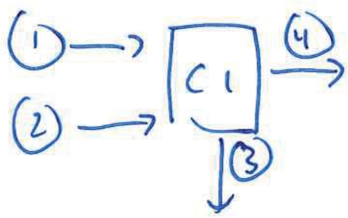
c) Calculate the total flow rate (kg/h) of stream 4. (/2)

$$W_B = 0.896 = \frac{\dot{M}_B}{\dot{M}_{TOTAL}} = \frac{450 \text{ kg/h}}{\dot{M}_{TOTAL}}$$

$$\boxed{\dot{M}_{TOTAL} = 502.23 \text{ kg/h}} = \dot{m}_4$$

d) Determine the total flow rate (kg/h) of stream 3. (/2)

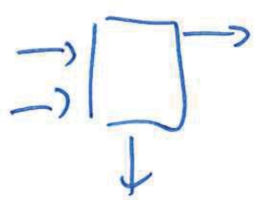
TOTAL BALANCE ON C1 ~~I/6=0/A~~



$$1000 + 500 = 502.23 + \dot{m}_3$$

$$\boxed{\dot{m}_3 = 997.77 \text{ kg/h}}$$

e) Determine the mass fractions of A and C in stream 4. (/4)



Balance on A

$$\dot{m}_1 W_A + \cancel{\dot{m}_2 W_A} = \dot{m}_3 W_A + \dot{m}_4 W_A$$

$$1000 \text{ kg/h} = 0.98(997.77) + \underbrace{502.23\, W_{A4}}_{22.1854}$$

$$\boxed{W_{A4} = 0.044}$$

STREAM 4

B – 450 kg/h
A – 22.1854
TOTAL – 502.23

$\rightarrow M_{C4} = 30.04$

$$W_{C4} = \frac{30.04}{502.23} = \boxed{0.06 = W_{C4}}$$

f) Determine molar flow rate of stream 4. (/4)

(4) A 22.1854 kg/h /18 = 1.233 kmol/h

B 450 kg/h /58 = 7.759 "

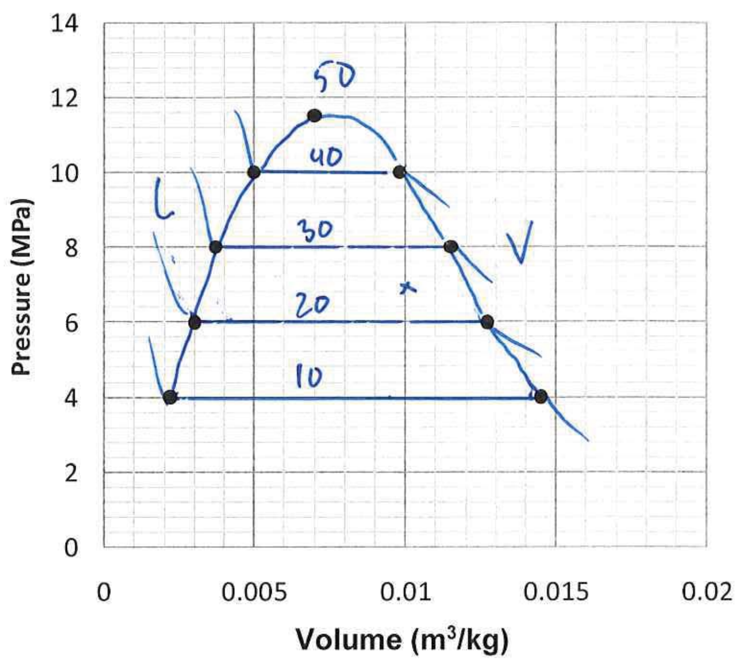
C 30.04 kg/h /29 = 1.036 "

$\boxed{10.03 \text{ kmol/h}}$

Question Number II *(25 Marks ~ 30 minutes)*

The following vapour-liquid equilibrium data are available for Sumonium with a molar mass of 50 kg/kmol. The triple point data for Sumonium is P=100kPa and T=2°C.

Temperature (°C)	Vapour Pressure (MPa)
10	4.0
20	6.0
30	8.0
40	10.0
50	11.5



a) Which phase or phases are present at 8MPa and 20°C? (/1)

LIQ

b) What phase of phases are present at 30°C and 4 MPa? (/1)

VAP

c) Which phase or phases are present at 8MPa and 51°C? (/1)

GAS

d) Which phase or phases are present at when 1 kg of Sumonium occupies 10,000 cm^3 at 25°C? (/2)

$$10{,}000\ cm^3 \times \left(\frac{1m}{100cm}\right)^3 = 0.01m^3 \quad V = \frac{0.01m^3}{1kg}$$

$\boxed{\text{VAP + LIQ}}$

e) A sample with 4 kg of liquid and 3 kg of vapour is held at equilibrium at 10°C. Use the phase rule to determine the degrees of freedom and a set of intensive variables that would fix the system. (/3)

$F = C + 2 - P$ $\quad C = 1$, $P = 2$

$F = 1 + 2 - 2$

$F = 1$ but $T = 10°C$ so $\boxed{F = 0}$ no variables

f) A rigid container (Box#1) holds 20 kg of liquid Sumonium at its bubble point at 40°C.

i. What is the pressure inside the box? (/1)

$P = P_{VAP} = \boxed{10 \text{ MPa}}$

ii. What is the volume of the box? (/2)

$V = 0.005 \frac{m^3}{kg} = \frac{v}{M} = \frac{v}{20 kg}$ $\quad \boxed{v = 0.1 \ m^3}$

iii. Next, 5 kg of Sumonium are removed from the box while keeping the temperature constant. What is the new pressure in the box? (/3)

new $M = 15$ kg $\quad v = 0.1 m^3$

$V = \frac{v}{M} = \frac{0.1 m^3}{15 kg} = 0.00667 m^3/kg \rightarrow V + L$

$\boxed{P \text{ still } 10 \text{ MPa}}$

iv. What is the mass of each phase present in part iii? (/4)

L	MIX	V
0.005	0.00667	0.0098

$\frac{M_L}{M_T} = \frac{0.0098 - 0.00667}{0.0098 - 0.005} = 0.652$

$0.652 \times 15 = \boxed{9.78 \text{ kg LIQ}}$

$M_V = 15 - 9.78 = \boxed{5.22 \text{ kg VAP}}$

g) At a pressure of 2 MPa and a temperature of 5°C it is known that an equimolar mixture of liquid and vapour occupy 5m^3. At these conditions the bubble point density is 666.667 kg/m^3, and the ratio of the specific volumes of vapour:liquid is 10:1.

i. Calculate the specific volumes of the co-existing liquid and vapour phases. (/3)

$n_L = n_V$ and $m_L = m_V$ $\quad \mathcal{V} = 5\,m^3$

$$\rho_L = 666.667\ kg/m^3 \longrightarrow V_L = \frac{1}{\rho_L} = \boxed{0.0015\ m^3/kg = V_L}$$

$$\frac{V_V}{V_L} = \frac{10}{1} \rightarrow V_V = 10 \times V_L = \boxed{0.015\ m^3/kg = V_V}$$

ii. Determine the volumes and masses of each phase present. (/4)

$m_L = m_V$ $\qquad V_L$ —— V_m —— V_V

$$\frac{m_L}{m_V} = 1 = \frac{V_V - V_m}{V_m - V_L} \rightarrow V_m - V_L = V_V - V_m$$

$$2V_m = V_V + V_L$$

$$V_m = \frac{V_V + V_L}{2} = \frac{0.0015 + 0.015}{2} = 0.00825\ m^3/kg$$

(mix)

$$V_m = \frac{\mathcal{V}}{m} \rightarrow \qquad m = \frac{\mathcal{V}}{V} = \frac{5\,m^3}{0.00825} = 606.06\ kg$$

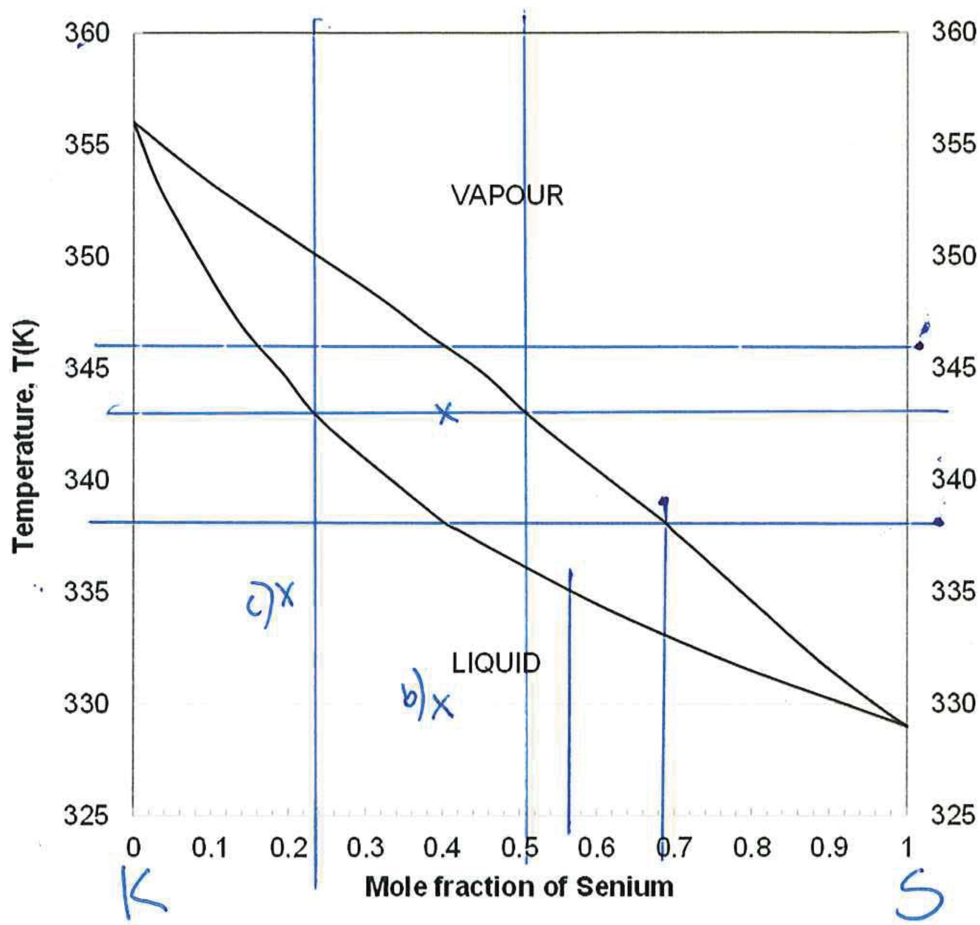
$$m_L = \frac{m}{2} = \boxed{303\ kg\ L} \text{ and } \boxed{303\ kg\ V}$$

$$V_L = \frac{\mathcal{V}_L}{m_L} \rightarrow \mathcal{V}_L = V_L m_L = 0.0015 \times 303 = \boxed{0.4545\ m^3\ \text{LIQ}}$$

$$\mathcal{V}_V = \mathcal{V} - \mathcal{V}_L = \boxed{4.545\ m^3\ \text{VAP}}$$

Question Number III *(25 Marks ~ 30 minutes)*

Use the temperature-composition phase diagram below at 1 atm pressure for a binary system composed of two components, called Senium (MW=58 kg/kmol) and Kallosium (MW=60 kg/kmol) to answer the following questions.



a) Answer the following questions about the system:

i. What is the boiling point of pure Senium at 1 atm? (/1)

329 K

ii. What is the dew point of an equimolar vapour mixture of Senium and Kallosium? (/2)

343 K

iii. What is the maximum temperature at which any mixture of Senium and Kallosium will remain as a liquid at 1 atm pressure? (/2)

329 K

iv. The mixture is an example of (choose one answer from below): (/1)

1. Completely miscible liquid with azeotrope
2. Completely miscible liquid without azeotrope
3. Partially miscible liquid with azeotrope
4. Partially miscible liquid without azeotrope

b) A mixture of Senium and Kallosium is at equilibrium at 330K and contains 40 kmol Senium and 60 kmol Kallosium.

i. Which phase is present and what is the composition (mole percent) of that phase? (/2)

$X_S = \frac{40}{100} = \boxed{0.40}$ $\boxed{\text{LIQUID}}$

ii. The mixture in part b) i is heated slowly until it reaches its bubble point. What is the amount (moles) and composition (in mole fraction) of the vapour? (/2)

Amount = fraction

$X_{se} = 0.68$

iii. The mixture is further heated slowly until it reaches 343 K. What phase or phases are present at equilibrium? (/1)

LIQ + VAP

iv. Determine are the composition and amount of the phases in part (iii) above. (/4)

$\boxed{\text{LIQ } X_{se} = 0.24 \,/\, \text{VAP } X_{se} = 0.51}$

L M V

0.24 0.40 0.51

$\frac{n_L}{n_T} = \frac{0.51 - 0.40}{0.51 - 0.24} = 0.407$

$n_L = 0.407 \times 100 = \boxed{40.7 \text{ kmol}}$

$n_V = 100 - n_L = \boxed{59.3 \text{ kmol}}$

v. The mixture in part (iv) above is heated further. At what temperature does the last drop of liquid disappear? (/1)

$\boxed{346 \text{ K}}$

c) Consider 10 kmol of mixture at 335 K and the mole fraction of Kallosium is 0.8.

i. Determine the mass of the mixture (in kg). (/2)

$X_{se} = 0.20$

10 kmol → 2 kmol S × 58 kg/kmol = 116 kg
→ 8 kmol K × 60 kg/kmol = 480 kg

$\boxed{596 \text{ kg}}$

ii. How much Senium (in kg) should be added to or removed from the container isothermally (335K) at 1 atm so that the mixture will just start to boil? (/4)

new $X_{se} = 0.56$ (move right so add Se)

n = added Se

$$0.56 = \frac{n_{se}}{n_{TOTAL}} = \frac{2 \text{ kmol} + n}{10 \text{ kmol} + n}$$

$$0.56(10 + n) = 2 + n$$

$$5.6 + 0.56n = 2 + n$$

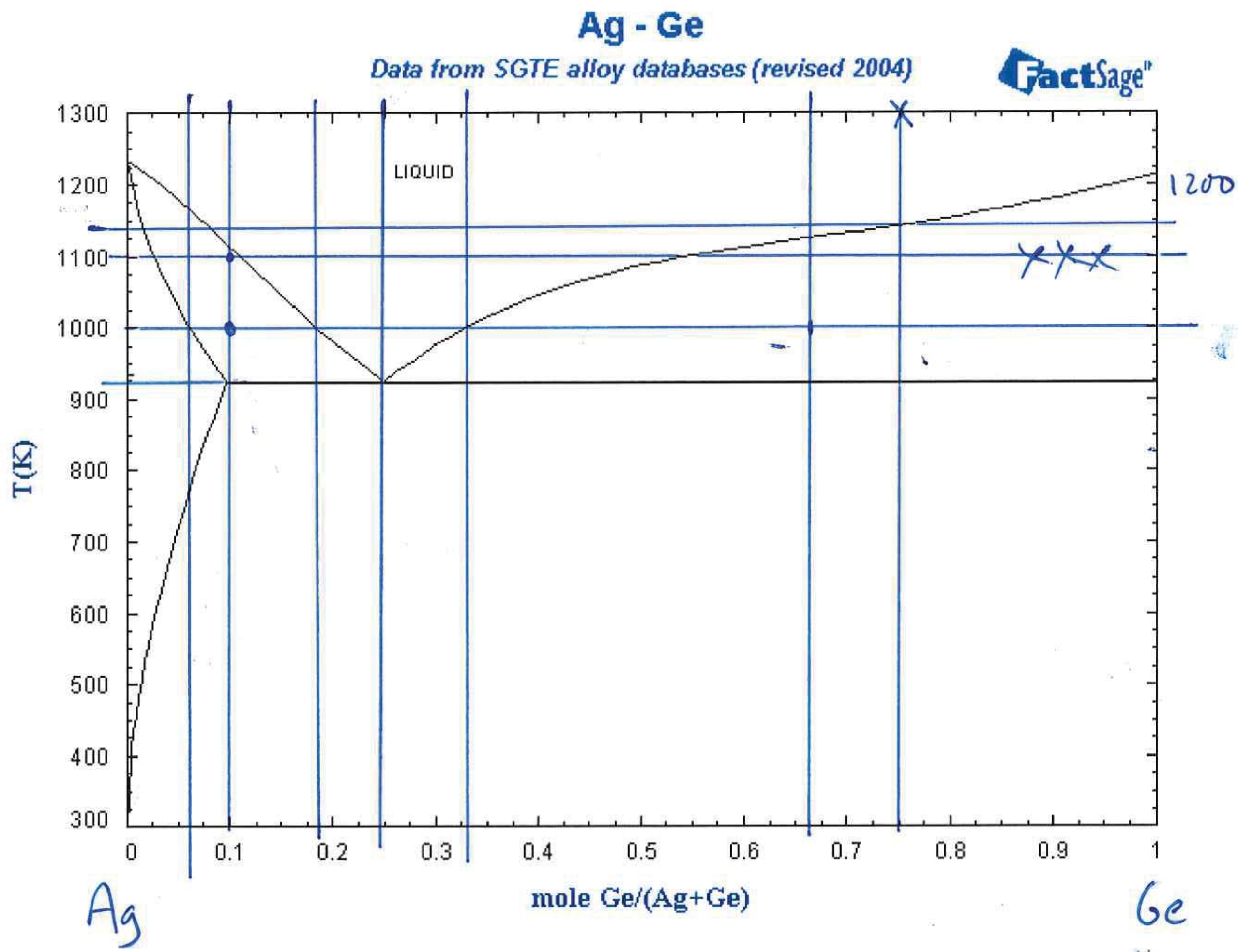
$$3.6 = 0.44n$$

$\boxed{n = 8.18 \text{ kmol Se added}}$

$8.18 \text{ kmol} \times 58 \frac{\text{kg}}{\text{kmol}} = \boxed{464 \text{ kg added}}$

Question Number IV *(25 Marks ~ 30 minutes)*

Use the phase diagram for the Silver (Ag) – Germanium (Ge) system at 1 atm below to answer the following questions. The molar mass of Silver is 107.87 kg/kmol and Germanium is 72.64 kg/kmol.



a) What is the melting point of pure Germanium at 1 atm? (/1)

~1212 K

b) What is the freezing point of pure Germanium at 1 atm? (/1)

~1212 K

c) What is the eutectic temperature and composition? (/2)

925 K and $X_{Ge} = 0.25$

d) What is the maximum solubility of silver in germanium? (/1)

$X_{Ag} = 0$

e) A mixture with 107.87 kg of Silver and 217.92 kg of Germanium is initially held at 1300K and is slowly cooled.

i. What is the mole fraction of silver in the mixture? (/3)

$n_{Ag} = \frac{107.87}{107.87} = 1\ \text{kmol} \qquad n_{Ge} = \frac{217.92}{72.64} = 3\ \text{kmol}$

$X_{Ag} = \frac{1}{1+3} = \boxed{0.25} \quad (X_{Ge} = 0.75)$

ii. At what temperature will the first solid appear? (/1)

$\sim 1130\ K$

iii. What is the composition of the first solid? (/1)

$X_{Ge} = 1.0$ (pure Ge)

iv. At what temperature will the last liquid disappear? (/1)

925 K (Eutectic T)

v. What is the composition of the last liquid? (/1)

$X_{Ge} = 0.25$ (Eutectic X)

f) A 20 kg mixture containing 10% germanium on a molar basis is held at 1100K.

i. Identify the phases present and calculate the moles of each phase. (/4)

$X_{Ge} = 0.10 \qquad T = 1100K$

SOLID β + LIQUID

$X_{Ge} = 0.06 \qquad X_{Ge} = 0.18$

20 kg mix (10% Ge molar)

$= 0.1917$ kmol (see next page)

S — MIX — L

0.06 — 0.10 — 0.18

$\frac{n_L}{n_T} = \frac{0.1-0.06}{0.18-0.06} = 0.333$

$n_L = 0.333 \times 0.1917$

$\boxed{0.0639\ \text{kmol}\ L}$

$\boxed{n_S = 0.1278\ \text{kmol}\ S}$

... continued

...continued

$X_{Ge} \rightarrow W_{Ge}$ 1 kmol $\rightarrow$ 0.10 kmol Ge × 72.64 = 7.264 ~~kmol~~ kg

$\rightarrow$ 0.90 kmol Ag × 107.87 = 97.083 ~~kmol~~ kg

104.347 kg

$$W_{Ge} = \frac{7.264}{104.347} = 0.0696$$

20 × 0.0696 = 1.392 kg Ge (20 − 1.392 = 18.608 kg Ag)

$$Ge \quad \frac{1.392}{72.64} = 0.0192 \text{ kmol Ge} \quad \frac{18.608}{107.87} = 0.1725 \text{ kmol Ag} \Rightarrow 0.1917 \text{ kmol total}$$

ii. Calculate the mass of Germanium in each phase. (/4)

LIQUID

0.0639 kmol × 0.18 = $\boxed{0.0115 \text{ kmol Ge}}$

× M_{Ge} = $\boxed{0.83536 \text{ kg Ge in LIQ}}$

SOLID

0.1278 kmol × 0.06 = $\boxed{0.007668 \text{ kmol Ge}}$

× M_{Ge} = $\boxed{0.557 \text{ kg Ge in SOLID}}$

iii. How much Germanium (moles) would you have to add to obtain a mixture containing equal moles of solid Germanium and liquid at 1000K. (/5)

$$\text{new } X_{Ge} = 0.66 = \frac{n_{Ge}}{n_T} = \frac{0.0192 + n}{0.1917 + n}$$

$$0.66(0.1917 + n) = 0.0192 + n$$

$$0.1265 + 0.66n = 0.0192 + n$$

$$0.1073 = 0.34n$$

$$\boxed{n = 0.3156 \text{ kmol Ge added}}$$

EXTRA WORK *(please mark clearly if you use this space for a particular question)*

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Useful Information

Volume cylinder: $v=\pi r^2 h$

Phase rule: $F+P = C+2$

$1\ L = 0.001\ m^3 = 1000\ cm^3$

QUESTION	Maximum Score	Student Score
1	25	
2	25	
3	25	
4	25	
TOTAL	100	