KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
Department of Chemical Engineering
B.Sc. Chemical Engineering,
MIDSEMESTER EXAMINATION
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**CHE 156: Physical Chemistry for Chemical Engineers** — **YEAR ONE**

***Answer All Questions*** — **TIME ALLOWED: ONE HOUR 30MINUTES**

***Solve the problem in the supplementary sheet provided and write your answer in the space provided***

1. A small bubble rises from the bottom of a lake, where the temperature and pressure are 50°F and 6.4atm, to the water's surface. If the temperature and pressure at the surface are 77°F and 1atm respectively. Calculate the final volume (in mL) of the bubble at the surface if its initial volume at the bottom of the lake was 2.1mL.

14.2mL

2. Calculate the root-mean square(rms) speed of $O_2$ molecule in m/s at 77°F ; (R=8.314 J/mol.K)

482 m/s

**Use the following information to answer problems 3 and 4**

Given that 2.50 moles of methane ($CH_4$) occupy 5.20L at 47°C, R=0.08205atm.L/mol.K

3. Calculate the pressure of the gas (in atm) using the ideal gas equation

12.62 atm

4. Calculate the pressure of the gas (in atm) using the Van der Waal's equation

12.37 atm

5. For a second order reaction, what is the unit of the rate constant?

$M^{-1} s^{-1}$

6. Calculate the standard enthalpy of formation of acetylene ($C_2H_2$) from its elements:

$$2C(graphite) + H_2(g) \rightarrow C_2H_2(g)$$

The equations for each step and the corresponding enthalpy changes are:

(i) $C(graphite) + O_2(g) \rightarrow CO_2(g)$ $\Delta H^o{}_{rxn} = -393.5KJ$

(ii) $2H_2 + O_2(g) \rightarrow 2H_2O(l)$ $\Delta H^o{}_{rxn} = -571.6KJ$

(iii) $2C_2H_2(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O(l)$ $\Delta H^o{}_{rxn} = -2598.8KJ$

226.6 kJ

7. A 0.2g sample of solid magnesium is burned in a constant-volume bomb calorimeter that has a heat capacity of 1769J/°C. The calorimeter contains exactly 300g of water, and the temperature increases by 1.126°C. Calculate the heat given off by the burning magnesium in kJ/mol.(mg=24.3g/mol, $s_{water}$=4.2J/g.°C)

414.4 kJ/mol

**Use the following information to answer problems 8 to 11**

A conversion of cyclopropane to propene in the gas phase is a first order reaction with a rate constant of 5.0x $10^{-4}$ $S^{-1}$ at 500°C.

8. If the initial concentration of cyclopropane was 0.25 M, what is the concentration after 8.8min?.

0.192 M

9. How long will it take for the concentration of cyclopropane to decrease from 0.25 M to 0.15M?

17 mins. (1022 sec)

10. How long will it take to convert 26% of the starting material?

10 mins. (602 sec)

Ques 1

$P_1 = 6.4\,atm$ $T_1 = 50°F$ $V_1 = 2.1\,mL$

$P_2 = 1\,atm$ $T_2 = 77°F$ $V_2 = ?$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$T_1\,°K = \frac{5}{9}(50-32)+273 = 283\,K$$

$$T_2\,°K = \frac{5}{9}(77-32)+273 = 298\,K$$

$$\Rightarrow V_2 = \frac{P_1 V_1 T_2}{P_2 T_1} = \frac{6.4\,\cancel{atm} \times 2.1\,mL \times 298\,\cancel{K}}{1\,\cancel{atm} \times 283\,\cancel{K}}$$

$$\boxed{V_2 = 14.2\,mL}$$ Ans.

Ques 2

$T = 77°F = 298\,K$

$$U_{rms} = \sqrt{\frac{3RT}{M}} \quad ; \quad M_{O_2} = 32\,g/mol$$

$$U_{rms} = \sqrt{\frac{3 \times 8.314 \frac{J}{\cancel{mol}\cdot\cancel{K}} \times 298\,\cancel{K}}{32\,g/\cancel{mol}}} = \sqrt{\frac{232.27\,\frac{Kg\,m^2}{s^2}}{\cancel{g}}}$$

$$\boxed{U_{rms} = 482\,m/s}$$ Ans.

FORMULAS

1. $Urms = \sqrt{\frac{3RT}{M}}$

2. Van der Waals equation = $\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$

3. For a first order reaction $t_{\frac{1}{2}} = \frac{0.693}{k}$; $\quad ln\frac{[A]}{[A_o]} = -kt$

4. For a second order reaction $t_{\frac{1}{2}} = \frac{1}{k[A_o]}$; $\quad \frac{1}{[A]} = \frac{1}{[A_o]} - kt$

5. Heat, $q = ms\Delta t$

6. For Arrhenius equation: $k = Ae^{-E_a/RT}$ ; $ln\frac{k_1}{k_2} = \frac{E_a}{R}\left(\frac{T_1 - T_2}{T_1T_2}\right)$

*van der Waals Constants for Various Gase*

| *Compound* | *a* *($L^2$-atm/mol$^2$)* | *b (L/mol)* |
|---|---|---|
| He | 0.03412 | 0.02370 |
| Ne | 0.2107 | 0.01709 |
| $H_2$ | 0.2444 | 0.02661 |
| Ar | 1.345 | 0.03219 |
| $O_2$ | 1.360 | 0.03803 |
| $N_2$ | 1.390 | 0.03913 |
| CO | 1.485 | 0.03985 |
| $CH_4$ | 2.253 | 0.04278 |
| $CO_2$ | 3.592 | 0.04267 |
| $NH_3$ | 4.170 | 0.03707 |

**B. AFOTEY**

11. Calculate the half- life of cyclopropane

23.1 mins. (1386 sec)

12. The rate at which tree crickets chirp is $2.0 \times 10^2$ per minute at 27°C but only 39.6 per minute at 5°C. From this data, calculate the activation energy for the chirping process.

51 KJ/mol

13. A mixture of gases contains 4.46 moles of Neon(Ne), 0.74 moles of Argon (Ar) and 2.15 moles of Xenon (Xe). Calculate the partial pressures ( in atm) of the gases if the total pressure is 4.0 atm at a certain temperature.

$P_{Ne} = 2.43$ atm. $P_{Ar} = 0.403$ atm; $P_{Xe} = 1.17$ atm.

14. The rate constant of a first-order reaction is $4.60 \times 10^{-4} s^{-1}$ at 350°C. If the activation energy is 104 kJ/mol, calculate the temperature at which its rate constant is $8.80 \times 10^{-4} s^{-1}$.

644 K (371 °C)

15. A flask contains a mixture of compounds A and B. Both compounds decompose by first order kinetics. The half-lives are 50.0 minutes for A and 18.0 minutes for B. If the concentrations of A and B are equal initially, how long will it take for the concentration of A to be four times that of B?

56.2 min (3373)

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Unit of $\boxed{k, = M^{-1} S^{-1}}$ Ans.

Ques 6

$$4C\,(\text{graphite}) + \cancel{4O_2}\,(g) \rightarrow \cancel{4CO_2}\,(g) \qquad \Delta H^\circ_{rxn} = \cancel{-393.5}\ -1{,}574\ kJ$$

$$2H_2 + \cancel{O_2}\,(g) \rightarrow \cancel{2H_2O}\,(l) \qquad \Delta H^\circ_{rxn} = -571.6\,kJ$$

$$\cancel{4CO_2}\,(g) + \cancel{2H_2O}\,(l) \rightarrow 2C_2H_2\,(g) + \cancel{5O_2}\,(g) \qquad \Delta H^\circ_{rxn} = 2598.8\,kJ$$

$$4C\,(\text{graphite}) + 2H_2 \rightarrow 2C_2H_2\,(g) \qquad \Delta H^\circ_{f} = 453.2\,kJ$$

Dividing by 2

$$\therefore\ 2C\,(\text{graphite}) + H_2 \rightarrow C_2H_2\,(g) \qquad \boxed{\Delta H^\circ_f = 226.6\,kJ}$$

Ques 7

$$\text{Heat},\ Q = C_{calo}\,\Delta T + m_{H_2O}\,S_{H_2O}\,\Delta T$$

$$Q = \left(1769\,J/\cancel{^\circ C} * 1.126\,\cancel{^\circ C}\right) + \left(300\,\cancel{g} \times 4.2\,J/\cancel{g}\,\cancel{^\circ C} \times 1.126\,\cancel{^\circ C}\right)$$

$$Q = 1991.894\,J + 1418.76\,J = 3410.654\,J$$

$$Q = 3.411\,kJ$$

$$\therefore\ \text{no of moles of } Mg = \frac{0.2\,g}{24.3\,g/mol} = 0.00823\,mol$$

$$\therefore\ \text{Heat given off} = \frac{3.411\,kJ}{0.00823\,mol} = \boxed{414.4\,kJ/mol}$$

$$\ln\left\{\frac{[A]}{[A]_0}\right\} = -kt \quad ; \quad k = 5.0\times10^{-4}\,s^{-1}$$

$$T = 500°C = 773K$$

$$\frac{[A]}{[A]_0} = e^{-kt} \quad ; \quad t = 8.8\,min \left| \frac{60\,sec}{1\,min} \right. = \underline{528\,sec.}$$

$$\therefore [A] = 0.25M \times e^{-(5.0\times10^{-4}/\cancel{s} \times 528\cancel{s})}$$

$$[A] = 0.25\,e^{-0.264}\,M.$$

$$\boxed{[A] = 0.192M}\ \text{Ans.}$$

Ques 9

$$\ln\left\{\frac{0.15}{0.25}\right\} = -5.0\times10^{-4} \times t$$

$$\Rightarrow t = 1022\,sec. \simeq 17.03\,min$$

$$\boxed{t = 17\,min.}\ \text{Ans.}$$

Ques 10

$$\ln\left\{\frac{0.74[A]_0}{[A]_0}\right\} = -5.0\times10^{-4}\,t$$

$$\Rightarrow t = 602.2\,sec \left| \frac{1\,min}{60\,sec} \right. = \underline{10\,min}.$$

$$\Rightarrow \boxed{t = 10\,min}\ \text{Ans}$$

moles, He = 4.46
moles, Ar = 0.74
moles Xe = 2.15

$P_T = 4.0$ atm.

$P_{He} = P_T X_{He}$

$P_{Ar} = P_T X_{Ar}$

$P_{Xe} = P_T X_{Xe}$

$n_T = 4.46 + 0.74 + 2.15$
$n_T = 7.35$ moles.

$\therefore X_{He} = \frac{4.46}{7.35} = 0.6068$

$X_{Ar} = \frac{0.74}{7.35} = 0.1007$

$X_{Xe} = \frac{2.15}{7.35} = 0.2925$

$P_{He} = 4 \times \frac{4.46}{7.35} = 2.43$ atm.

$P_{Ar.} = 4 \times \frac{0.74}{7.35} = 0.403$ atm.

$P_{Xe} = 4 \times \frac{2.15}{7.35} = 1.17$ atm.

$P_{He} = 2.43$ atm ; $P_{Ar} = 0.403$ atm ; $P_{Xe} = 1.17$ atm. Ans.

Ques 14

$k_1 = 4.6 \times 10^{-4} s^{-1}$ ; $T_1 = 350°C = 623K$ ; $E_a = 104\ kJ/m$

$k_2 = 8.80 \times 10^{-4} s^{-1}$ $T_2 = ?$ $R = 8.314\ J/mol.K$

$$\ln\left\{\frac{4.6 \times 10^{-4} s^{-1}}{8.80 \times 10^{-4} s^{-1}}\right\} = \frac{104 \times 10^3\ \cancel{J}/\cancel{mol}}{8.314\ \cancel{J}/\cancel{mol}.K}\left(\frac{623 - T_2}{623 \times T_2}\right)$$

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$$t_{1/2} = \frac{0.693}{5 \times 10^{-4} s^{-1}} = 1386 \text{ sec}$$

$$\boxed{t_{1/2} = 23.1 \text{ min}}$$ Ans.

Ques 12

$$\ln \frac{k_1}{k_2} = \frac{E_a}{R}\left(\frac{T_1 - T_2}{T_1 T_2}\right)$$

$k_1 = 2.0 \times 10^2/\text{min}$ ; $T_1 = 27°C = 300 K$

$k_2 = 39.6/\text{min}$ ; $T_2 = 5°C = 278 K$.

$$\ln \left\{\frac{200/\cancel{min}}{39.6/\cancel{min}}\right\} = \frac{E_a}{8.314 \, J/\cancel{K}.mol}\left(\frac{300-278}{300 \times 278}\right)\frac{\cancel{K}}{K^{\cancel{2}}}$$

$$E_a = \frac{1.6195 \times 8.314 \, J/mol}{2.638 \times 10^{-4}}$$

$$E_a = 51,043 \, J/mol$$

$$\boxed{E_a = 51.043 \, KJ/mol}$$ Ans.

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$PV = nRT$

$$P = \frac{nRT}{V} \quad ; \quad T = 47^\circ C = 320K.$$

$$P = \frac{2.5 \cancel{moles} \times 0.08205 \frac{atm.L}{\cancel{mol}.\cancel{K}} \times 320\cancel{K}}{5.20L}$$

$$\boxed{P = 12.62 \text{ atm.}}$$ Ans.

## Ques 4

For $CH_4$, $a = 2.253 \frac{L^2\text{-atm}}{mol^2}$ ; $b = 0.04278 \frac{L}{mol}$.

$$\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$$

$$\left(P + \frac{2.253 \frac{\cancel{L^2}\text{-atm}}{\cancel{mol^2}} \times (2.5 \cancel{mol})^2}{(5.2\cancel{L})^2}\right)\left(5.2L - 2.5\cancel{mol} \times 0.04278 \frac{L}{\cancel{mol}}\right)$$

$$= 2.5 \cancel{moles} \times 0.08205 \frac{atm.L}{\cancel{mol}.\cancel{K}} \times 320\cancel{K}$$

$$(P + 0.5208 \text{ atm})(5.09305 L) = 65.64 \text{ atm L}$$

$$P = \frac{65.64 \text{ atm} \cancel{L}}{5.09305 \cancel{L}} - 0.5208 \text{ atm}.$$

$$\boxed{P = 12.37 \text{ atm}}$$ Ans.

$$-0.6487 = 12{,}509.02 \times \left(\frac{623 - T_2}{623 \cdot T_2}\right).$$



$$-5.186 \times 10^{-5} = \frac{623 - T_2}{623\, T_2}$$

$$-0.03231\, T_2 = 623 - T_2$$

$$T_2 - 0.03231\, T_2 = 623$$

$$T_2 = \frac{623}{1 - 0.03231} = 643.8 = 644\,K.$$

$$\boxed{T_2 = 644\,K = 371^\circ C} \text{ Ans.}$$

**Ques 15**

$t_{1/2\text{-}A} = 50$ min $= 3000$ sec.

$t_{1/2\text{-}B} = 18$ min $= 1080$ sec.

$$k_A = \frac{0.693}{3000} = 2.31 \times 10^{-4}\, s^{-1}$$

$$\ln\left\{\frac{[A]}{[A]_0}\right\} = -kt$$

$$\ln\left\{\frac{[B]}{[A]_0}\right\} = -kt$$

$$\ln\left\{\frac{[A]}{[A]_0}\right\} = -2.31 \times 10^{-4}\, t_A$$

$$k_B = \frac{0.693}{1080} = 6.42 \times 10^{-4}$$

$$\ln\left\{\frac{[B]}{[B]_0}\right\} = -6.42 \times 10^{-4} \cdot t_B$$

Also at ~~last~~ $t_A = t_B = t$,

but initially $[B]_0 = [A]_0$

$$[A] = 4[B]$$

$$[B] = \frac{1}{4}[A]$$

8

$$\ln\left\{\frac{[A]}{[A]_0}\right\} = -2.31\times10^{-4}\,t \quad \text{—} (1)$$

$$\ln\left\{\frac{[A]/4}{[A]_0}\right\} = -6.42\times10^{-4}\,t \quad \text{—} (2)$$

From (1) $\ln[A] - \ln[A]_0 = -2.31\times10^{-4}\,t$ — (3)

From (2) $\ln[A] - \ln[4] - \ln[A]_0 = -6.42\times10^{-4}\,t$

$\Rightarrow \ln[A] - \ln[A]_0 = \ln[4] - 6.42\times10^{-4}\,t$ — (4)

$\Rightarrow$ left eqns. ~~等~~ are equal (3) = (4)

$$\Rightarrow -2.31\times10^{-4}\,t = \ln 4 - 6.42\times10^{-4}\,t$$

$$6.42\times10^{-4}\,t - 2.31\times10^{-4}\,t = 1.3863$$

$$t = \frac{1.3863}{6.42\times10^{-4} - 2.31\times10^{-4}}$$

$$\boxed{t = 3373 \text{ sec.} = 56.2 \text{ min}}$$ Ans.

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