January 28th, 2020

First Hour Test
Chemistry 20B
Winter 2020

Name _____   UID_____

Problem	Points Possible	Points Scored
1	20	
2	25	
3	25	
4	30	
Total	100	

BE SURE TO SHOW ALL YOUR REASONING AND CALCULATIONS!

DO NOT WRITE ON THE BACK OF THE EXAM
AN EXTRA PAGE HAS BEEN ADDED FOR EACH QUESTION

PLEASE WORK IN PEN OR WRITE DARKLY IN PENCIL

DEMONSTRATING CLEARLY HOW YOU ARRIVE AT YOUR ANSWER IS MORE IMPORTANT THAN THE NUMERICAL ANSWER ITSELF

AND PLEASE BE CAREFUL WITH UNITS:
NEVER GIVE A NUMERICAL ANSWER WITHOUT UNITS

CHECK THE LAST PAGE FOR EQUATIONS AND CONSTANTS

PLEASE CROSS OUT ANY WORK YOU DO NOT WANT US TO GRADE

1. (20 pts) a. Rank the following three molecules according to the relative strengths of their intermolecular forces: H_2, CO, and KF? Explain your reasoning considering each molecule interacting with another one of itself.

b. Draw a rough sketch of the potential energy versus separation distance for each molecule (PLEASE PLOT ALL THREE ON THE SAME GRAPH). Indicate the appropriate axes and indicate the relative depths and relative positions of the minima.

c. Rank the following three molecules in order of increasing boiling point: H_2, CO, and KF? Explain your answer.

(a) H_2 is weakest because the molecule has no electronegativity difference, so the IMF between H_2 is induced-dipole induced-dipole forces, which are the weakest IMF.

CO is second-weakest because $EN_O - EN_C = 3.4 - 2.6 = 0.8$, meaning that the IMF between CO molecules is dipole-dipole forces of intermediate strength.

KF is strongest because $EN_F - EN_K = 4 - 0.8 = 3.2$, meaning that the IMF between KF molecules is ionic forces, which are the strongest type of IMF.

So overall, the relative strength is: $H_2 < CO < KF$.
(in terms of IMF)

(b)

$\sigma_{KF} > \sigma_{CO} > \sigma_{H_2}$ because KF is the largest molecule, followed by CO, then H_2.

$\varepsilon_{KF} > \varepsilon_{CO} > \varepsilon_{H_2}$ because KF has the strongest IMF, followed by CO, then H_2
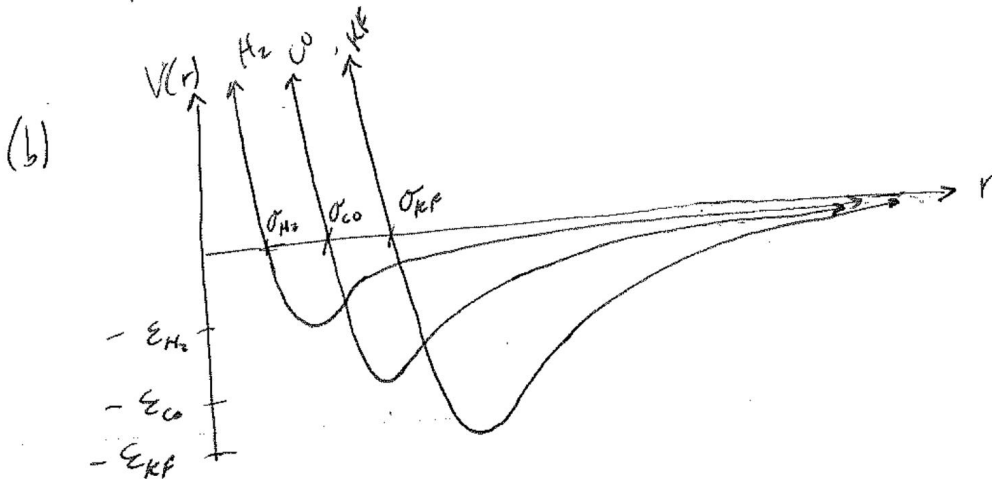
(c) For boiling point, $H_2 < CO < KF$

This is because KF exhibits the strongest IMF and therefore the deepest curve in the graph in part b. It thus requires the highest energy input (ie the highest boiling point) to separate its molecules. The same reasoning applies for CO and H_2, with H_2 having the lowest boiling point because it requires the least energy input to overcome its weak induced-dipole induced-dipole IMF, and CO being intermediate in boiling point due to its intermediate bond IMF strength.

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2. (25 pts) The gas phase reaction $A_{(g)} \rightleftharpoons 2B_{(g)} + C_{(g)}$ occurs in a sealed 100 ml balloon sitting in a room at atmospheric pressure and temperature (1 atm and 293K). Initially, the ~~flask~~ balloon contains only gas A.

   a. Determine the initial amount (in moles) of A present in the ~~flask.~~ balloon
   b. Assume that the reaction proceeds to completion (no A remains). What are the partial pressures of B and C (in units of atm) once the reaction is complete?
   the rxn ...c. At equilibrium, what is the new volume of the balloon?
   d. Calculate the reversible work done by the gas inside the balloon.
   e. If the reaction produced 1 kJ of heat, calculate the enthalpy of the reaction in units of kJ/mol.

Answers:

a.	b.	c.	d.	e.
$= 4.16 \times 10^{-3}$ mol	$P_B = 0.667$ atm $P_C = 0.333$ atm	$V = 3 \times 10^{-4}$ m^3	$W_{gas} = 20.3$ J	$\Delta H_{rxn} = 240$ kJ/mol

$V = 100$ mL
$P = 1$ atm
$T = 293$ K

(a) $PV = nRT$

$$n_A = \frac{PV}{RT} = \frac{(1 \text{ atm})(101325 \text{ Pa/atm})(100 \text{ mL})(10^{-3} \text{ L/mL})(10^{-3} \text{ m}^3/\text{L})}{(8.314 \frac{J}{mol \cdot k})(293 \text{ k})}$$

$$n_A = 4.16 \times 10^{-3} \text{ mol}$$

(b) Because the balloon is in equilibrium:
$1 \text{ atm} = P_B + P_C = 2P_C + P_C$
$1 \text{ atm} = 3P_C$
$P_C = \frac{1}{3}\frac{P}{A} = \frac{1}{3} \text{ atm} = 0.333 \text{ atm}$

$P_B = 2P_C$
$P_B = \frac{2}{3} \text{ atm} = 0.667 \text{ atm}$

(c) $T = 293$ K
$P_{total} = P_B + P_C = 1$ atm
1 mol reactant → 3 mol product; so $n_{total} = 3n_A$

$PV = nRT$

$$V = \frac{n_{total} RT}{P_{total}} = \frac{3n_A RT}{P_{total}}$$

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$$V = \frac{3(4.16 \times 10^{-3} \text{ mol})(8.314 \frac{J}{mol \cdot k})(293 \text{ k})}{(1 \text{ atm})(101325 \text{ Pa/atm})} = 3 \times 10^{-4} \text{ m}^3$$

(d) $V_i = 100$ mL

$V_f = 3 \times 10^{-4}$ m^3

$P_{ext} = 1$ atm

$w = -\int P_{ext} \, dV$

$= -P_{ext} \int dV$

$= -P_{ext}(V_f - V_i)$

$= -(1 \text{ atm})(101325 \text{ Pa/atm}) \times$
$[3 \times 10^{-4} - (100 \text{ mL})(10^{-3} \text{ L/mL})(10^{-3} \text{ m}^3/\text{L})]$

$= -20.3$ J

↗

work done by surroundings...

Because the process is reversible:

$w_{gas} = -w_{surr} = -(-20.3 \text{ J}) = 20.3$ J

(c) $q = 1$ kJ

$q = n \Delta H_{rxn}$

$\Delta H_{rxn} = \dfrac{q}{n} = \dfrac{1 \text{ kJ}}{n_A} = \dfrac{1 \text{ kJ}}{4.16 \times 10^{-3} \text{ mol}} = 240$ kJ/mol

3. (25 pts) Determine the amount of ice in grams (T_{ice} = -5°C) required to cool a 500 ml glass of soda from 25°C to 5°C. The heat capacity of soda is the same as water ($4.2 \frac{J}{g°C}$), the heat capacity of ice is 2.1 $\frac{J}{g°C}$, the enthalpy of fusion of water is 334 $\frac{J}{g}$, and the density of soda is the same as water ($1000 \frac{g}{L}$).

Answer:

$$M_{ice} = 115 \ g$$

$T_{ice} = -5°C$

$V_s = 500 \ ml$

$V_{si} = 25°C$

$V_{sf} = 5°C$

$C_s = 4.2 \frac{J}{g°C}$

$C_{ice} = 2.1 \frac{J}{g°c}$

$\Delta H = 334 \frac{J}{g}$

$P_s = 1000 \frac{g}{L}$

$T_{sf} = 5°c$

$T_{si} = 25°c$

Find mass of soda:

$M_s = V_s P_s = (500 \ ml)(10^{-3} \ L/ml)(1000 \ g/L)$

$= 500 \ g$

Heat is exchanged, so:

$q_s + q_{ice} = 0$

$M_s C_s \Delta T_s + [\underbrace{M_{ice} C_{ice}(0°C + 5°C)}_{heat \ ice} + \underbrace{M_{ice} \Delta H}_{melt \ ice} + \underbrace{M_{ice} C_w (5°c - 0°c)}_{heat \ water}] = 0$

$M_{ice} = \dfrac{- M_s C_s \Delta T_s}{C_{ice}(0°C + 5°c) + \Delta H + C_w(5°c - 0°c)}$

$M_{ice} = \dfrac{- (500 \ g)(4.2 \frac{J}{g°c})(5°c - 25°c)}{(2.1 \frac{J}{g°c})(5°c) + (334 \frac{J}{g}) + (4.2 \frac{J}{g°c})(5°c)}$

$M_{ice} = 115 \ g$

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4. (30 pts) A balloon that is equilibrated in a room at 1 atm and 300K has a volume of 10 L.
   a. Determine the pressure inside the balloon.
   b. Calculate the number density of the gas inside the balloon.
   c. Assuming it's a sphere, calculate the force exerted on the surface of the balloon.
   d. If the room is pressurized from 1 atm to 10 atm at 300K, determine the balloons new equilibrium volume.
   e. The balloon from parts a and b is placed back in a room at 300K. If the room is heated from 300K to 310K at 1 atm, ~~and the internal energy of the monatomic ideal gas inside the balloon increased by 10 Joules (J)~~, determine the work done by the gas.

Answers:

a.	b.	c.	d.	e.
$P_{inside} = 1$ atm $= 101325$ Pa	$\frac{N}{V} = 2.45 \times 10^{25}$ m^{-3}	$F = 2.27 \times 10^4$ N	$V = 0.001$ m^3	$W_{gas} = 33.8$ J

$P_{ext} = 1$ atm
$T = 300$ K
$V = 10$ L

(a) The balloon is equilibrated, so we know that:

$$P_{inside} = P_{ext} = 1 \text{ atm}$$
$$= 101325 \text{ Pa}$$

(b) $PV = Nk_BT$

$$\frac{N}{V} = \frac{P}{k_BT} = \frac{(1 \text{ atm})(101325 \text{ Pa/atm})}{(1.38 \times 10^{-23} \frac{J}{k})(300 \text{ K})} = 2.45 \times 10^{25} \text{ m}^{-3}$$

(c) $P = \frac{F}{A} \longrightarrow F = PA$

$$F = P(4\pi r^2)$$

Find r:
$$V = \frac{4}{3}\pi r^3$$
$$r = \left(\frac{3V}{4\pi}\right)^{\frac{1}{3}} = \left(\frac{3(10 \text{ L})(10^{-3} \text{ m}^3/\text{L})}{4\pi}\right)^{\frac{1}{3}}$$
$$r = 0.13365 \text{ m}$$

$$F = (1 \text{ atm})(101325 \text{ Pa/atm})(4\pi r^2) \longleftarrow$$

$$F = 2.27 \times 10^4 \text{ N}$$

(d) $\Delta T = 0$
$P_f = 10$ atm
$T = 300$ K

\# moles:
$$n = \frac{P_iV_i}{RT_i} = \frac{(1 \text{ atm})(101325 \text{ Pa/atm})(10 \text{ L})(10^{-3} \text{ m}^3/\text{L})}{(8.314 \frac{J}{mol \cdot k})(300 \text{ K})}$$
$$n = 0.406 \text{ mol}$$

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$$V_f = \frac{nRT}{P_f} = \frac{(0.406 \text{ mol})(8.314 \frac{J}{mol \cdot k})(300 \text{ K})}{(10 \text{ atm})(101325 \text{ Pa/atm})} = 0.001 \text{ m}^3$$

(e) $T_i = 300 \text{ K}$

$T_f = 310 \text{ K}$

$P = 1 \text{ atm}$

$\Delta U = \frac{3}{2} nR\Delta T = q + W$

$\frac{3}{2} nR\Delta T = nC_p \Delta T + W$

$\frac{3}{2} nR\Delta T - n\left(\frac{5}{2}R\right)\Delta T = W$

$W = \frac{3}{2} nR\Delta T - \frac{5}{2} nR\Delta T$

$W = -nR\Delta T$

$W = -(0.406 \text{ mol})\left(8.314 \frac{J}{mol \cdot K}\right)(310 \text{ K} - 300 \text{ K})$

$W = -33.8 \text{ J}$

↑

work done by surroundings

$W_{gas} = -W_{surr} = -(-33.8 \text{ J})$

$W_{gas} = 33.8 \text{ J}$