

last name

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signature

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|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| 1                  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    | 18                 |                    |                    |                    |                    |                    |                    |
| 1<br>H<br>1.008    |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    | 2<br>He<br>4.003   |                    |                    |                    |                    |                    |                    |
| 3<br>Li<br>6.941   | 4<br>Be<br>9.012   |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    | 5<br>B<br>10.81    | 6<br>C<br>12.01    | 7<br>N<br>14.01    | 8<br>O<br>16.00    | 9<br>F<br>19.00    | 10<br>Ne<br>20.18  |
| 11<br>Na<br>22.99  | 12<br>Mg<br>24.31  |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    | 13<br>Al<br>26.98  | 14<br>Si<br>28.09  | 15<br>P<br>30.97   | 16<br>S<br>32.07   | 17<br>Cl<br>35.45  | 18<br>Ar<br>39.95  |
| 19<br>K<br>39.10   | 20<br>Ca<br>40.08  | 21<br>Sc<br>44.96  | 22<br>Ti<br>47.87  | 23<br>V<br>50.94   | 24<br>Cr<br>52.00  | 25<br>Mn<br>54.94  | 26<br>Fe<br>55.85  | 27<br>Co<br>58.93  | 28<br>Ni<br>58.69  | 29<br>Cu<br>63.55  | 30<br>Zn<br>65.38  | 31<br>Ga<br>69.72  | 32<br>Ge<br>72.64  | 33<br>As<br>74.92  | 34<br>Se<br>78.96  | 35<br>Br<br>79.90  | 36<br>Kr<br>83.80  |
| 37<br>Rb<br>85.47  | 38<br>Sr<br>87.62  | 39<br>Y<br>88.91   | 40<br>Zr<br>91.22  | 41<br>Nb<br>92.91  | 42<br>Mo<br>95.94  | 43<br>Tc<br>(98)   | 44<br>Ru<br>101.07 | 45<br>Rh<br>102.91 | 46<br>Pd<br>106.42 | 47<br>Ag<br>107.87 | 48<br>Cd<br>112.41 | 49<br>In<br>114.82 | 50<br>Sn<br>118.71 | 51<br>Sb<br>121.76 | 52<br>Te<br>127.60 | 53<br>I<br>126.90  | 54<br>Xe<br>131.29 |
| 55<br>Cs<br>132.91 | 56<br>Ba<br>137.33 | 57<br>La<br>138.91 | 72<br>Hf<br>178.49 | 73<br>Ta<br>180.95 | 74<br>W<br>183.84  | 75<br>Re<br>186.21 | 76<br>Os<br>190.23 | 77<br>Ir<br>192.22 | 78<br>Pt<br>195.08 | 79<br>Au<br>196.97 | 80<br>Hg<br>200.59 | 81<br>Tl<br>204.38 | 82<br>Pb<br>207.20 | 83<br>Bi<br>208.98 | 84<br>Po<br>(209)  | 85<br>At<br>(210)  | 86<br>Rn<br>(222)  |
| 87<br>Fr<br>(223)  | 88<br>Ra<br>(226)  | 89<br>Ac<br>(227)  | 104<br>Rf<br>(267) | 105<br>Db<br>(268) | 106<br>Sg<br>(269) | 107<br>Bh<br>(270) | 108<br>Hs<br>(270) | 109<br>Mt<br>(278) | 110<br>Ds<br>(281) | 111<br>Rg<br>(282) | 112<br>Cn<br>(285) | 113<br>Nh<br>(286) | 114<br>Fl<br>(289) | 115<br>Mc<br>(290) | 116<br>Lv<br>(293) | 117<br>Ts<br>(294) | 118<br>Og<br>(294) |

|                    |                    |                    |                   |                    |                    |                    |                    |                    |                    |                    |                    |                    |                    |
|--------------------|--------------------|--------------------|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| 58<br>Ce<br>140.12 | 59<br>Pr<br>140.91 | 60<br>Nd<br>144.24 | 61<br>Pm<br>(145) | 62<br>Sm<br>150.36 | 63<br>Eu<br>151.96 | 64<br>Gd<br>157.25 | 65<br>Tb<br>158.93 | 66<br>Dy<br>162.50 | 67<br>Ho<br>164.93 | 68<br>Er<br>167.26 | 69<br>Tm<br>168.93 | 70<br>Yb<br>173.04 | 71<br>Lu<br>174.97 |
| 90<br>Th<br>232.04 | 91<br>Pa<br>231.04 | 92<br>U<br>238.03  | 93<br>Np<br>(237) | 94<br>Pu<br>(244)  | 95<br>Am<br>(243)  | 96<br>Cm<br>(247)  | 97<br>Bk<br>(247)  | 98<br>Cf<br>(251)  | 99<br>Es<br>(252)  | 100<br>Fm<br>(257) | 101<br>Md<br>(258) | 102<br>No<br>(259) | 103<br>Lr<br>(266) |

constants

$R = 0.08206 \text{ L atm/mol K}$

$R = 0.08314 \text{ L bar/mol K}$

$R = 62.36 \text{ L Torr/mol K}$

$R = 8.314 \text{ L kPa/mol K}$

$R = 8.314 \text{ J/mol K}$

$N_A = 6.022 \times 10^{23} / \text{mol}$

conversions

$1 \text{ atm} = 760 \text{ torr}$

$1 \text{ atm} = 14.7 \text{ psi}$

$1 \text{ atm} = 101325 \text{ Pa}$

$1 \text{ atm} = 1.01325 \text{ bar}$

$1 \text{ bar} = 10^5 \text{ Pa}$

$^{\circ}\text{F} = ^{\circ}\text{C}(1.8) + 32$

$\text{K} = ^{\circ}\text{C} + 273.15$

conversions

$1 \text{ in} = 2.54 \text{ cm}$

$1 \text{ ft} = 12 \text{ in}$

$1 \text{ yd} = 3 \text{ ft}$

$1 \text{ mi} = 5280 \text{ ft}$

$1 \text{ lb} = 453.6 \text{ g}$

$1 \text{ ton} = 2000 \text{ lbs}$

$1 \text{ tonne} = 1000 \text{ kg}$

$1 \text{ gal} = 3.785 \text{ L}$

$1 \text{ gal} = 231 \text{ in}^3$

$1 \text{ gal} = 128 \text{ fl oz}$

$1 \text{ fl oz} = 29.57 \text{ mL}$

$1 \text{ Troy oz} = 31.104 \text{ g}$

water data

$C_{s,\text{ice}} = 2.09 \text{ J/g } ^{\circ}\text{C}$

$C_{s,\text{water}} = 4.184 \text{ J/g } ^{\circ}\text{C}$

$C_{s,\text{steam}} = 2.03 \text{ J/g } ^{\circ}\text{C}$

$\rho_{\text{water}} = 1.00 \text{ g/mL}$

$\rho_{\text{ice}} = 0.9167 \text{ g/mL}$

$\rho_{\text{seawater}} = 1.024 \text{ g/mL}$

$\Delta H_{\text{fus}} = 334 \text{ J/g}$

$\Delta H_{\text{vap}} = 2260 \text{ J/g}$

$k_f = 1.86 \text{ } ^{\circ}\text{C}/m$

$k_b = 0.512 \text{ } ^{\circ}\text{C}/m$

$K_w = 1.0 \times 10^{-14}$

This exam should have exactly 25 questions. Each question is equally weighted at 4 points each. You will enter your answer choices on the virtual bubbleseet after you have finished. Your score is based on what you submit on the virtual bubblesheet and not what is circled on the exam.

1. You take a plane from Austin, TX (Weather: 760 Torr, 80 °F) to Denver, CO (Weather: 630 Torr, 30 °F) and develop several symptoms - dizziness, headache, and nausea - all characteristic of altitude sickness, which is typically attributed to a lack of oxygen in the blood stream. Which of the following answer choices correctly explains this unfortunate phenomenon?

- a. The lower  $P_{O_2}$  in Denver means less oxygen can dissolve into blood.
- b. The colder air in Denver means more oxygen can dissolve into blood.
- c. The colder air in Denver means less oxygen can dissolve into blood.
- d. The lower  $P_{O_2}$  in Denver means more oxygen can dissolve into blood.
- e. It is impossible to say.

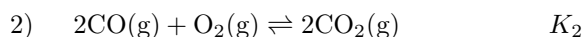
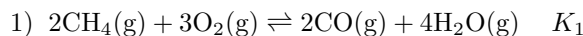
**Explanation:** The air temperature is irrelevant for this problem, your body maintains a constant temperature of 37°C or 98.6 °F. On the other hand, the partial pressure of oxygen in the atmosphere is very important. The reduction of air pressure in denver results in less oxygen dissolving into the bloodstream, leading to the symptoms associated with altitude sickness.

2. You add some sodium hydroxide pellets into a beaker of room temperature water and stir it until it dissolves. You then attempt to pick up the beaker and find that it is too hot to comfortably handle. Which of the following answer choices regarding the enthalpy of dissolution are consistent with this observation?

- a.  $\Delta H_{\text{lattice}} = +890 \text{ kJ}$ ;  $\Delta H_{\text{solvation}} = -890 \text{ kJ}$
- b.  $\Delta H_{\text{lattice}} = +890 \text{ kJ}$ ;  $\Delta H_{\text{solvation}} = -930 \text{ kJ}$
- c.  $\Delta H_{\text{lattice}} = +890 \text{ kJ}$ ;  $\Delta H_{\text{solvation}} = -889 \text{ kJ}$
- d.  $\Delta H_{\text{lattice}} = +930 \text{ kJ}$ ;  $\Delta H_{\text{solvation}} = -890 \text{ kJ}$
- e. It is impossible to say without knowing what  $\Delta S_{\text{solution}}$  is.

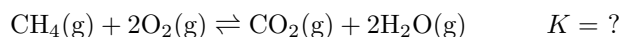
**Explanation:** The problem statement implies that the dissolution of sodium hydroxide is exothermic. Thus,  $\Delta H_{\text{solvation}}$  is greater in magnitude than  $\Delta H_{\text{lattice}}$ .

3. Consider the stepwise oxidation of methane into  $\text{CO}_2$ :



Where  $K_1 = 3.77 \times 10^4$ , and  $K_2 = 6.46 \times 10^9$

Find  $K$  for the overall reaction below:



- a.  $K = 1.56 \times 10^7$
- b.  $K = 5.83 \times 10^{28}$
- c.  $K = 4.11 \times 10^{-15}$
- d.  $K = 2.43 \times 10^{14}$
- e.  $K = 7.73 \times 10^{17}$
- f.  $K = 6.41 \times 10^{-8}$

**Explanation:** When we add reactions together, we multiply the equilibrium constants to find the new equilibrium constant. The important thing to recognize here is that adding rxn 1 to rxn 2 gives the desired reaction, but doubled. Thus, after multiplying the equilibrium constants together, we must then take the square root. This gives  $K = (K_1 K_2)^{1/2}$ .

4. How much heat must be removed (you are cooling here) to cool a 60 g sample of steam at 150 °C to liquid water at 40 °C?

- a. 156.7 kJ
- b. 166.8 kJ
- c. 191.3 kJ
- d. 127.5 kJ
- e. 141.6 kJ

**Explanation:**  $\Delta H = mc_{\text{steam}}\Delta T + m\Delta H_{\text{vap}} + mc_{\text{water}}\Delta T = -(60)(2.03)(50) - (60)(2260) - (60)(4.184)(60) = -156.7 \text{ kJ}$

5. Consider the reaction

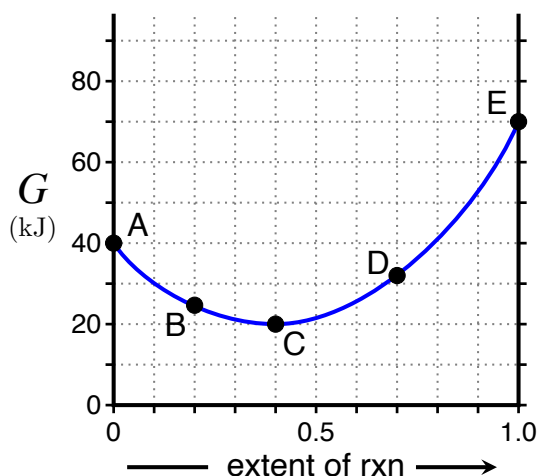


If the concentration of A is tripled, what will happen to the value of  $K$ ?

- a.  $K$  increases by a factor of nine.
- b.  $K$  increases by a factor of three.
- c.  $K$  does not change.
- d.  $K$  decreases by one-ninth.
- e.  $K$  decreases by one-third.
- f.  $K$  increases because the reaction will shift toward the product side to relieve the stress.

**Explanation:** For any given reaction at a given temperature,  $K$  is, by definition, a constant.

6. (Part 1 of 2) Consider the following free energy vs extent of reaction diagram.



What is the standard free energy ( $\Delta G^\circ$ ) for this reaction?

- a. +80 kJ
- b. -50 kJ
- c. -40 kJ
- d. -20 kJ
- e. +50 kJ
- f. +30 kJ

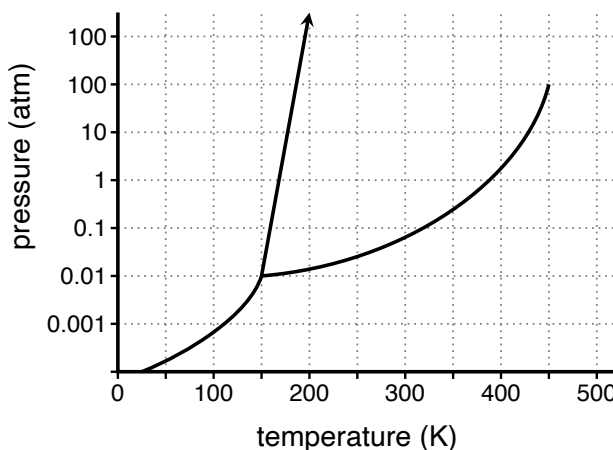
**Explanation:** The standard free energy change is just the free energy of the products (point E) minus the free energy of the reactants (point A).  $70 - 40 = +30$  kJ

7. (Part 2 of 2) Refer to the previous extent of reaction diagram. A mixture exists with the amounts that correspond to point D on the diagram. Which statement is true as the mixture proceeds to equilibrium?

- a.  $Q$  is greater than  $K$  and the reaction goes in reverse to point C.
- b.  $Q$  is greater than  $K$  and the reaction goes in reverse to point A.
- c.  $Q$  is less than  $K$  and the reaction goes forward to point E.
- d.  $Q$  is equal to  $K$  and the reaction is at equilibrium.
- e.  $Q$  is less than  $K$  and the reaction goes in reverse to point C.

**Explanation:** The equilibrium point is C which has the lowest free energy mixture of reactants and products. Point D has too many products vs C and therefore  $Q > K$ . The reaction must reverse to go from D to C.

8. (Part 1 of 2) Consider the following phase diagram



What is the normal boiling point of this substance?

- a. 170 K
- b. 385 K
- c. 320 K
- d. 450 K
- e. 430 K
- f. 150 K

**Explanation:** Follow the 1 atm line (normal) to the liquid/gas line. That intersection is at 385 K which is the boiling point at that pressure.

9. (Part 2 of 2) Referring to the previous phase diagram, I keep the temperature constant at 300 K and then steadily reduce the applied pressure from 1 atm down to 0.001 atm. What best describes what I observe?

- A solid will begin melting until all of it is a liquid.
- A liquid will begin freezing until all of it solidifies.
- A liquid will boil until about half of it is gas and the rest is liquid.
- A gas will begin condensing until all of it is a liquid.
- A liquid will just remain a liquid.
- A liquid will begin boiling until all of it is a gas.

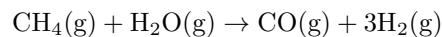
**Explanation:** Following the vertical line at 300 K from 1 atm down to 0.001 atm, we cross the liquid-gas line which means boiling occurred (while on the line) and we completely make it to gas state. All of it is gas at 0.001 atm.

10. Road salt (typically sodium chloride) is added to roads in icy conditions to melt the ice. To test this out, you dissolve 200 g of sodium chloride into 1 L of water and place it into a freezer. What is the new freezing point of this salty solution?

- $T_{\text{fp}} = +6.4^{\circ}\text{C}$
- $T_{\text{fp}} = -3.5^{\circ}\text{C}$
- $T_{\text{fp}} = +12.7^{\circ}\text{C}$
- $T_{\text{fp}} = -6.4^{\circ}\text{C}$
- $T_{\text{fp}} = -1.8^{\circ}\text{C}$
- $T_{\text{fp}} = -12.7^{\circ}\text{C}$

**Explanation:**  $\Delta T_f = i \cdot k_f \cdot m$ ; where  $m$  is molality. For water,  $k_f = 1.86^{\circ}\text{C m}^{-1}$ . The molality (mol/kg solvent) is  $(200 \text{ g NaCl})(1 \text{ mol NaCl}/58.44 \text{ g})/(1 \text{ kg water}) = 3.42 \text{ m}$ . Thus,  $\Delta T_f = 2 \cdot 1.86 \cdot 3.42 = 12.7$ , making the new freezing point  $-12.7^{\circ}\text{C}$ .

11. Steam reforming converts methane into the industrially useful 'syngas' by the following reaction:



Given that the reaction is highly endothermic, select the correct choice regarding the spontaneity of this process.

- The reaction is only spontaneous at high temperatures.
- The reaction is never spontaneous at any temperature.
- The reaction is spontaneous at all temperatures.
- The reaction is only spontaneous at low temperatures.

**Explanation:** We are told that  $\Delta H > 0$ , and from the stoichiometry of the reaction it can be determined that  $\Delta S > 0$ . Thus, using our expression for Gibbs' free energy ( $\Delta G = \Delta H - T\Delta S$ ) we see that the reaction will only be spontaneous at high temperatures, where the entropic driving force overcomes the enthalpic penalty for this process.

12. Using a process known as plasmid vectorization, E. coli cells can be programmed to produce a wide variety of complicated molecules, including antibiotics and proteins. Anyway, which of the following should we do to break open the cells and obtain our desired molecule?

- Place the cells into water with an osmotic pressure similar to that found inside the cell.
- Place the cells into very salty water.
- None of the other options will burst the cells.
- Place the cells into pure water.
- Sing them a lovely song.

**Explanation:** E. coli cells contain electrolytes as well as small molecules which give them an internal osmotic pressure. Adding the cells to pure water allows water to diffuse into the cells to balance the osmotic pressure gradient, causing them to swell and eventually burst.

13. Mojo Jojo, archenemy of the Powerpuff Girls, gives you some of the coveted Chemical X. Intrigued, you measure the boiling point here in Austin (local air pressure = 1.0 atm) and find it to be 77°C. You then take a plane to Nepal and miraculously climb Mount Everest to its summit. At an elevation of 8848 m (local air pressure = 0.33 atm) you measure the boiling point and find it to be 44°C. What is the enthalpy of vaporization for Chemical X?

- a. 3.73 kJ/mol
- b. 52.5 kJ/mol
- c. 306 kJ/mol
- d. 946 kJ/mol
- e. 0.938 kJ/mol
- f. 31.0 kJ/mol

**Explanation:** Use the Clausius-Clapeyron equation. Let  $P_1$  and  $T_1$  represent one set of measurements, such as those in Austin. Let  $P_2$  and  $T_2$  represent the other measurements, in Nepal. Be sure that  $T$  is in Kelvin. Solve for  $\Delta H_{\text{vap}}$ , which will be a positive value because a substance must absorb energy in order to change phase to vapor.

14. Identify the van't Hoff factors ( $i$ ) for the following substances: glucose ( $\text{C}_6\text{H}_{12}\text{O}_6$ ), maltose ( $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ ), sodium chloride (NaCl), and calcium chloride ( $\text{CaCl}_2$ ).

- a.  $i_{\text{glucose}} = 1$ ,  $i_{\text{maltose}} = 2$ ,  $i_{\text{NaCl}} = 2$ ,  $i_{\text{CaCl}_2} = 3$
- b.  $i_{\text{glucose}} = 1$ ,  $i_{\text{maltose}} = 1$ ,  $i_{\text{NaCl}} = 2$ ,  $i_{\text{CaCl}_2} = 2$
- c.  $i_{\text{glucose}} = 1$ ,  $i_{\text{maltose}} = 1$ ,  $i_{\text{NaCl}} = 2$ ,  $i_{\text{CaCl}_2} = 4$
- d.  $i_{\text{glucose}} = 1$ ,  $i_{\text{maltose}} = 1$ ,  $i_{\text{NaCl}} = 2$ ,  $i_{\text{CaCl}_2} = 3$
- e.  $i_{\text{glucose}} = 1$ ,  $i_{\text{maltose}} = 1$ ,  $i_{\text{NaCl}} = 1$ ,  $i_{\text{CaCl}_2} = 1$

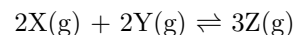
**Explanation:** Glucose and maltose are both non-electrolytes, thus their van't Hoff factors are both 1. NaCl dissociates into 2 ions, thus its factor is 2, while  $\text{CaCl}_2$  dissociates into 3 ions, thus its factor is 3.

15. You are the proud owner of a classic 1969 Chevy Camaro. On a particularly cold morning (0°C) you are unable to start your car, so you decide to spray some starting fluid into the carburetor. Success, your car starts! The bottle states that the starting fluid is 1 part diethyl ether (mw = 74.1 g/mol) to 1 part heptane (mw = 100.2 g/mol) by mass. Now, calculate the partial pressure of diethyl ether vapor assuming  $P_{\text{ether}}^\circ = 185$  Torr at 0 °C.

- a. 80 Torr
- b. 185 Torr
- c. 211 Torr
- d. 124 Torr
- e. 106 Torr

**Explanation:** This is a Raoult's law problem.  $P_{\text{ether}} = \chi_{\text{ether}} P_{\text{ether}}^\circ$ . We need to find  $\chi_{\text{ether}}$ . 1 part to 1 part by mass just means you use the exact same masses for each of the two fuels for the starting fluid. Let's pick 100.2 g for each of the two. Convert that mass into moles of each.  $n_{\text{ether}} = 100.2/74.1 = 1.35$  mol ether.  $n_{\text{heptane}} = 100.2/100.2 = 1.00$  mol heptane (see why I picked 100.2 g now?).  $\chi_{\text{ether}} = 1.35/(1.35+1.00) = 0.574$ .  $P_{\text{ether}} = (0.574)(185 \text{ Torr}) = 106 \text{ Torr}$ .

16. Consider the equilibrium:

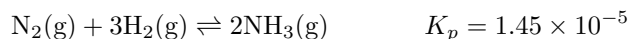


You introduce some X and Y into the reaction vessel and allow the system to equilibrate. The final partial pressures of each component were found to be  $P_{\text{X}} = 0.88$  atm,  $P_{\text{Y}} = 2.11$  atm,  $P_{\text{Z}} = 6.55$  atm. Calculate  $K_p$ .

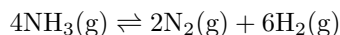
- a. 0.081
- b. 0.284
- c. 12.4
- d. 3.52
- e. 0.012
- f. 81.5

**Explanation:** Know how to set up an equilibrium expression, from there it is plug and chug.  $K_p = \frac{(P_{\text{Z}})^3}{(P_{\text{X}})^2(P_{\text{Y}})^2} = \frac{(6.55)^3}{(0.88)^2(2.11)^2} = 81.5$ .

17. The Haber-Bosch process generates ammonia by the following reaction:



at 500°C Now, calculate the equilibrium constant for this reaction:



- a.  $K_p = 4.76 \times 10^9$
- b.  $K_p = 7.22 \times 10^3$
- c.  $K_p = 6.90 \times 10^4$
- d.  $K_p = 1.45 \times 10^{-5}$
- e.  $K_p = 5.18 \times 10^7$
- f.  $K_p = 1.37 \times 10^5$

**Explanation:** We have taken the reaction, flipped it, and doubled it. Thus,  $K_{\text{new}} = 1/K_{\text{old}}^2$ .

18. Consider the reaction:

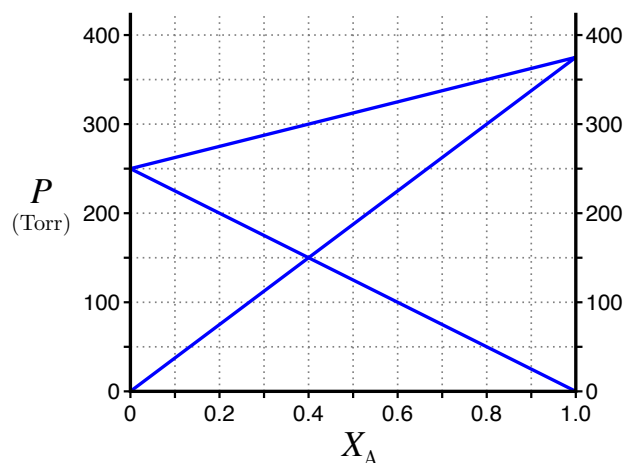


$K_p$  for this reaction is 0.44 at a temperature of 239 °C. What is the value of  $\Delta G^\circ$  for this reaction as shown?

- a. -1.63 kJ/mol
- b. -2.85 kJ/mol
- c. +3.50 kJ/mol
- d. +1.63 kJ/mol
- e. -3.50 kJ/mol
- f. +2.85 kJ/mol

**Explanation:**  $\Delta G^\circ = -RT \ln K$   
 $= -8.314(239 + 273.15) \ln(0.44) = 3500 \text{ J/mol}$

19. Consider the following vapor pressure diagram for a binary liquid of A and B:



The number of moles of A and B are adjusted such that the vapor pressure of A and B are exactly the same pressure. Which of the following mixes will satisfy this condition?

- a. 3 mol A + 2 mol B
- b. 2 mol A + 3 mol B
- c. 1 mol A + 1 mol B
- d. 1 mol A + 2 mol B
- e. 2 mol A + 1 mol B

**Explanation:** The only point on the diagram where the vapor pressure of A and B match is at 150 Torr (the intersection of the two lines). This is 0.4 mole fraction of A and therefore 0.6 mole fraction of B. That is a 2 to 3 ratio of A to B.

20. What are the signs for the change in enthalpy and change in entropy when dissolving a gas into a liquid?

- a.  $\Delta H > 0, \Delta S > 0$
- b.  $\Delta H < 0, \Delta S < 0$
- c.  $\Delta H < 0, \Delta S > 0$
- d.  $\Delta H > 0, \Delta S < 0$

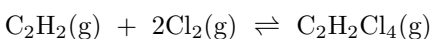
**Explanation:**  $\Delta H < 0$  because we are forming favorable IMFs between the gas molecules and solvent molecules, whereas there are essentially zero favorable IMFs in the gas phase. This ultimately releases energy, and the process is exothermic.  $\Delta S < 0$  because gas molecules dissolved into a liquid are more ordered than undissolved gas molecules.

21. Rank the following chemicals in terms of increasing miscibility in water ( $\text{H}_2\text{O}$ ): heptane ( $\text{C}_7\text{H}_{16}$ ), butanol ( $\text{C}_4\text{H}_9\text{OH}$ ), butyraldehyde ( $\text{CH}_3(\text{CH}_2)_2\text{CHO}$ ), and chlorobutane ( $\text{C}_4\text{H}_9\text{Cl}$ ).

- a. heptane < butanol < chlorobutane < butyraldehyde
- b. heptane < butyraldehyde < chlorobutane < butanol
- c. chlorobutane < heptane < butyraldehyde < butanol
- d. butanol < butyraldehyde < chlorobutane < heptane
- e. heptane < chlorobutane < butyraldehyde < butanol

**Explanation:** Remember, like dissolves like. The most similar solvent to water is butanol, with its ability to hydrogen bond. Next is butyraldehyde, with its polar C=O bond. Chlorobutane is slightly polar, but little is likely to dissolve in water. Heptane is very non-polar and will mix incredibly poorly with water. Thus, the order is heptane < chlorobutane < butyraldehyde < butanol.

22. (Part 1 of 2) You are performing the chlorination of acetylene in a piston-cylinder reactor. The reaction shown below is currently at equilibrium.



You now perturb the system by depressing the cylinder, halving the total volume of the system. Which answer choice below describes how the system reacts to this change?

- a. Generate more  $\text{C}_2\text{H}_2$  and  $\text{Cl}_2$
- b. Generate more  $\text{Cl}_2$ , but not more  $\text{C}_2\text{H}_2$
- c. Nothing changes
- d. Generate more  $\text{C}_2\text{H}_2$ , but not more  $\text{Cl}_2$
- e. Consume some  $\text{C}_2\text{H}_2\text{Cl}_4$
- f. Generate more  $\text{C}_2\text{H}_2\text{Cl}_4$

**Explanation:** Compressing a gas-system will shift the equilibrium toward the side with fewer gas molecules. Thus, the only correct choice is to generate more  $\text{C}_2\text{H}_2\text{Cl}_4$ .

23. (Part 2 of 2) Considering the same equilibrium reaction/system as above, what would happen if you instead injected enough  $\text{Cl}_2$  which would double its partial pressure.?

- a. Nothing changes
- b.  $P_{\text{C}_2\text{H}_2\text{Cl}_4}$  will increase
- c.  $P_{\text{C}_2\text{H}_2}$  will increase
- d.  $P_{\text{Cl}_2}$  will continue increasing
- e.  $P_{\text{C}_2\text{H}_2\text{Cl}_4}$  will decrease
- f.  $P_{\text{C}_2\text{H}_2}$  will increase and  $P_{\text{Cl}_2}$  will decrease

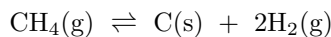
**Explanation:** Le'Chatelier's principle! If we perturb the system by adding more  $\text{Cl}_2$ , we will drive the system to generate more products. Thus, the only correct answer is that  $P_{\text{C}_2\text{H}_2\text{Cl}_4}$  will increase.

24. Rank the following chemicals in order of increasing vapor pressure: acetone ( $(\text{CH}_3)_2\text{CO}$ ), isopropanol ( $(\text{CH}_3)_2\text{CHOH}$ ), isobutane ( $(\text{CH}_3)_3\text{CH}$ ), dimethyl ether ( $\text{CH}_3\text{OCH}_3$ )

- a. dimethyl ether < acetone < isopropanol < isobutane
- b. isopropanol < acetone < dimethyl ether < isobutane
- c. isopropanol < dimethyl ether < acetone < isobutane
- d. isobutane < dimethyl ether < acetone < isopropanol
- e. acetone < isopropanol < dimethyl ether < isobutane

**Explanation:** Identify the strongest IMFs for each molecule. Acetone (highly polar, strong dipole-dipole), isopropanol (H-bonding), isobutane (London dispersion), dimethyl ether (weakly polar, weak dipole-dipole). Based on this information, we would expect isopropanol to be least volatile (H-bonding is the strongest IMF present). Acetone is more polar than dimethyl ether, thus acetone will be less volatile. Isobutane only possesses London dispersion forces, the weakest of all IMFs, thus it will be the most volatile.

25. Some alternative methods for hydrogen production have been proposed. One such process utilizes a molten bismuth catalyst to produce hydrogen without generating  $\text{CO}_2$ . What is correct equilibrium expression for this reaction?



- a.  $\frac{P_{\text{CH}_4}}{2P_{\text{H}_2}}$
- b.  $\frac{P_{\text{CH}_4}}{(P_{\text{H}_2})^2}$
- c.  $\frac{2P_{\text{H}_2}}{P_{\text{CH}_4}}$
- d.  $\frac{(P_{\text{H}_2})^2}{P_{\text{CH}_4} \cdot P_{\text{C}}}$
- e.  $\frac{P_{\text{CH}_4} \cdot P_{\text{C}}}{(P_{\text{H}_2})^2}$
- f.  $\frac{(P_{\text{H}_2})^2}{P_{\text{CH}_4}}$

**Explanation:** Solids (and liquids) are not included in equilibrium expressions (their activities are 1). Thus, the correct answer does not include the  $\text{C}(\text{s})$ . So only two terms are included in the mass action expression and you get  $\frac{(P_{\text{H}_2})^2}{P_{\text{CH}_4}}$ .

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After you are finished and have all your answers circled, go to the front of the room and then use the QR code show below to pull up the virtual answer page for your exam. Enter the appropriate info plus all your answers - click the SUBMIT button. Double check your choices on the next page. Once your are sure, click the submit button on that page to enter your answers. Make sure you get the confirmation screen (different background color!) and show it to the TA or proctor. After that, turn in your exam and scratch paper. You're free to leave after that.



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