Exam #1 Multiple Choice Answers

1. B
2. B
3. B
4. A
5. C
6. A
7. D
8. C
9. D
10. A
11. (extra credit) E
12. (extra credit) B

Exam #1 Written Problem Solutions

13. Carbon tetrachloride, CCl_4, has a vapor pressure of 213 torr at 40 °C and 836 torr at 80 °C. What is the normal boiling point of CCl_4?

Relating vapor pressures at different temperatures, need to use Clausius-Clapeyron equation:

$$\ln\left(\frac{P_1}{P_2}\right)=\frac{\Delta H_{vap}}{R}\left(\frac{1}{T_2}-\frac{1}{T_1}\right)$$

Don't know ΔH_{vap}, need to use data to calculate:

P_1 = 213 torr T_1 = 40 °C = 313 K ΔH_{vap} = ?

P_2 = 836 torr T_2 = 80 °C = 353 K

Plug-in values, solve for ΔH_{vap}:

$$\ln\left(\frac{213\text{ torr}}{836\text{ torr}}\right)=\frac{\Delta H_{vap}}{8.314\ \text{J}/\text{mol}\cdot\text{K}}\left(\frac{1}{353\text{ K}}-\frac{1}{313\text{ K}}\right)\qquad \Delta H_{vap}=3.14\times10^{4}\ \text{J}/\text{mol}$$

Now with ΔH_{vap} known, can calculate vapor pressure at new temperature:

P_1 = 213 torr T_1 = 40 °C = 313 K ΔH_{vap} = 3.14×10⁴ J/mol

P_2 = 760 torr T_2 = ?

$$\ln\left(\frac{P_1}{P_2}\right)=\frac{\Delta H_{vap}}{R}\left(\frac{1}{T_2}-\frac{1}{T_1}\right)$$

$$\ln\left(\frac{213\text{ torr}}{760\text{ torr}}\right)=\frac{3.14\times10^{4}\ \text{J}/\text{mol}}{8.314\ \text{J}/\text{mol}\cdot\text{K}}\left(\frac{1}{T_2}-\frac{1}{313\text{ K}}\right)$$

$$-3.368\times10^{-4}=\frac{1}{T_2}-\frac{1}{313\text{ K}}$$

$$\frac{1}{T_2}=2.858\times10^{-3}$$

$$\boxed{T_2=350\text{ K}=76.9\text{ °C}}$$

14. Heptane (C_7H_{16}, 100.21 g/mol) and octane (C_8H_{18}, 114.23 g/mol) are constituents of gasoline. At 80 °C, the vapor pressure of heptane is 428 torr and the vapor pressure of octane is 175 torr. What is the mole fraction of heptane in a mixture of heptane and octane that has a vapor pressure of 305 torr at 80 °C?

Raoult's law describes the vapor pressure of a mixture of volatile components:

$$P_{total}=\chi_{heptane}P^{\circ}_{heptane}+\chi_{octane}P^{\circ}_{octane}$$

Definition of mole fraction:

$$\chi_{heptane}+\chi_{octane}=1\qquad \chi_{octane}=1-\chi_{heptane}$$

Substitute into first expression and solve for mole fraction of heptane:

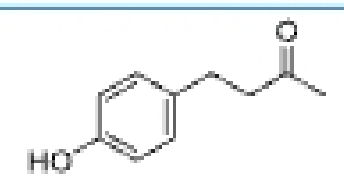
$$P_{total}=\chi_{heptane}P^{\circ}_{heptane}+(1-\chi_{heptane})P^{\circ}_{octane}$$

$$P_{total}=\chi_{heptane}P^{\circ}_{heptane}+P^{\circ}_{octane}-\chi_{heptane}P^{\circ}_{octane}$$

$$P_{total}-P^{\circ}_{octane}=\chi_{heptane}(P^{\circ}_{heptane}-P^{\circ}_{octane})$$

$$\chi_{cyclopentane}=\frac{P_{total}-P^{\circ}_{octane}}{P^{\circ}_{heptane}-P^{\circ}_{octane}}=\frac{305\text{ torr}-175\text{ torr}}{428\text{ torr}-175\text{ torr}}=\boxed{0.514}$$

15. The smell of ripe raspberries is due to 4-(*p*-hydroxyphenyl)-2-butanone, which has the empirical formula C_5H_6O. To find its molecular formula, you dissolve 0.135 g in 25.0 g chloroform, $CHCl_3$. The boiling point of the solution is 61.82 °C. What is the molecular formula of the solute? (normal boiling point for $CHCl_3$ = 61.70 °C; K_b = 3.63 °C/*m*)



4-(p-hydroxyphenyl)-2-butanone
Chemical Formula: $C_{10}H_{12}O_2$
Exact Mass: 164.08
Molecular Weight: 164.20
m/z: 164.08 (100.0%), 165.09 (10.8%)
Elemental Analysis: C, 73.15; H, 7.37; O, 19.49

Relationship for boiling point elevation:

$$\Delta T_b=iK_bm$$

Can solve for molality to get eventually to molecular weight/fomula,

$$m=\frac{\Delta T_b}{iK_b}=\frac{61.82\text{ °C}-61.70\text{ °C}}{(1)(3.63\text{ °C}/m)}=0.03305\ m\text{ raspberry smell}$$

Use molality as a conversion factor to get to mol raspberry smell

$$35.0\text{ g CHCl}_3\times\frac{1\text{ kg}}{1000\text{ g}}\times\frac{0.03305\text{ mol raspberry smell}}{1\text{ kg CHCl}_3}=8.264\times10^{-4}\text{ mol raspberry smell}$$

Relationship for molar mass:

$$MM=\frac{\text{g}}{\text{mol}}=\frac{0.135\text{ g raspberry smell}}{8.264\times10^{-4}\text{ mol raspberry smell}}=163.55\text{ g/mol}$$

To find molecular formula from empirical formula, figure out ratio between them:

$$MM\text{ of }C_5H_6O=5(12)+6(1)+1(16)=82\text{ g/mol}$$

Actual MM is twice, so multiple empirical formula by 2: $\boxed{C_{10}H_{12}O_2}$

16. For the vaporization of benzene at its normal boiling point, ΔH_{vap} = 30.8 kJ/mol and ΔS_{vap} = 87.2 J/mol·K. Does 1 mol benzene evaporate spontaneously in a beaker heated to 100 °C? ***Calculate ΔS_{univ} to justify your answer.***

for a spontaneous process: $\Delta S_{univ} = \Delta S_{sys} + \Delta S_{surr} > 0$

benzene = system; beaker = surroundings:

$$\Delta S_{univ} = \Delta S_{benzene} + \Delta S_{beaker}$$

for melting phase change:

$$\Delta S_{benzene} = n\Delta S_{vap}$$

So,

$$\Delta S_{univ} = n\Delta S_{vap} + \Delta S_{beaker}$$

But,

$$\Delta S_{beaker} = \frac{q_{beaker}}{T_{beaker}}$$

Then,

$$\Delta S_{univ} = n\Delta S_{vap} + \frac{q_{beaker}}{T_{beaker}}$$

Assume from First Law of Thermodynamics:

$$q_{benzene} = -q_{beaker}$$

Again, benzene is undergoing a phase change,

$$q_{benzene} = n\Delta H_{vap}$$

So,

$$q_{benzene} = -n\Delta H_{vap}$$

Substituting into expression for ΔS_{univ},

$$\Delta S_{univ} = n\Delta S_{vap} - \frac{n\Delta H_{vap}}{T_{beaker}}$$

Plug-in values,

$$\Delta S_{univ} = (1\,\text{mol})(87.2\,\text{J}/\text{mol}\cdot\text{K}) - \frac{(1\,\text{mol})(30.8\times10^3\,\text{J}/\text{mol})}{373\,\text{K}} = \boxed{4.63\,\text{J}/\text{K}}$$

ΔS_{univ} > 0, so yes benzene does evaporate spontaneously at 100 °C

17. A rocket fuel would be useless if its oxidation were not spontaneous. Although rockets operate under conditions that are far from standard, an initial estimation of the potential of a rocket fuel might assess whether its oxidation at the high temperatures reached in a rocket is spontaneous. A chemist exploring potential fuels for use in space considered using vaporized aluminum chloride in a reaction for which the unbalanced equation is:

$$4\ AlCl_3(g) + 9\ O_2(g) \rightarrow 2\ Al_2O_3(s) + 12\ ClO(g)$$

Substance	$\Delta G_f°$(kJ/mol)
$AlCl_3(g)$	–467
$O_2(g)$	0
$Al_2O_3(s)$	–1034
$ClO(g)$	75

Balance the equation, then use the data provided in the table (which are for 2000 K) to decide whether the fuel is worth further investigating. ***Explain your decision.***

Need to calculate ΔG_{rxn}: $\Delta G_{rxn} = \sum n\cdot\Delta G_f^\circ(\text{products}) - \sum n\cdot\Delta G_f^\circ(\text{reactants})$

$$\Delta G_{rxn} = \left[(2\,\text{mol})\left(-1034\frac{\text{kJ}}{\text{mol}}\right) + (12\,\text{mol})\left(75\frac{\text{kJ}}{\text{mol}}\right)\right] - \left[(4\,\text{mol})\left(-467\frac{\text{kJ}}{\text{mol}}\right) + 0\right] = \boxed{+700\,\text{kJ}}$$

A reaction that has ΔG_{rxn} that has such a large positive value is extremely unfavored thermodynamically. This particular reaction is nonspontaneous at 2000 K, so another reaction perhaps would be better explored.