2014 Academic Challenge Sectional Chemistry Exam Solution Set

1. E. A V-shaped molecule is possible in either the trigonal planar or the tetrahedral electron group geometry (A or B).

2. B. The fact that the pack feels cold means it is absorbing heat from its surroundings. This is characteristic of an endothermic reaction, which specifies a positive ΔH.

3. B. Water and ether can form hydrogen bonds with water acting as the H-bond donor, and the lone pairs on the ether oxygen acting as the H-bond acceptor.

4. B. Given the 1:1 ratio of sodium and chloride in NaCl:

$$150.0\text{ g mixture} * \frac{18.79\text{ g Na}}{100\text{ g mixture}} * \frac{1\text{ mol Na}}{22.99\text{ g Na}} * \frac{1\text{ mol Cl}}{1\text{ mol Na}} * \frac{35.45\text{ g Cl}}{1\text{ mol Cl}} = 43.46\text{ g Cl in mixture}$$

$$\frac{43.46\text{ g Cl}}{150.0\text{ g mixture}} * 100\% = 28.97\%\text{ Cl by mass}$$

5. A. Mass percent of oxygen in each compound: A = 89%; B = 68%; C = 76%; D = 64%; E = 53%.

6. E. $0.1000\text{ L }CaCl_2 * \frac{0.125\text{ mol }CaCl_2}{1\text{ L}} * \frac{1\text{ mol }Ca^{2+}}{1\text{ mol }CaCl_2} + 0.1500\text{ L }Ca_3N_2 * \frac{0.100\text{ mol }Ca_3N_2}{1\text{ L}} * \frac{3\text{ mol }Ca^{2+}}{1\text{ mol }Ca_3N_2}$
= 0.0575 mol Ca^{2+}
0.0575 mol Ca^{2+}/(0.1000 L + 0.1500 L) = 0.230 M Ca^{2+}.

7. A. For an ideal gas: $\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$. Solving for P_2: $P_2 = \frac{P_1V_1n_2T_2}{V_2n_1T_1}$. According to the problem, $n_1 = n_2$ (closed container); $V_2 = 2.6*V_1$; $T_2 = 0.5*T_1$. Substituting into the above equation: $P_2 = \frac{P_1V_1n_1 0.5*T_1}{2.6*V_1n_1T_1}$ and canceling like terms: $P_2 = \frac{P_1*0.5}{2.6} = \frac{433\text{ mm Hg}*0.5}{2.6} = 83.3\text{ mm Hg}$.

8. C. For a cooling object, the heat released (q) must be equal to the specific heat capacity times the mass times the change in temperature: q = m*c*ΔT. If heat is released, q must be a negative number: -5278 J = 35.0 g*c_{solid}*(25.9 ^oC – 85.0 ^oC). Solving for c_{solid} gives a value of 2.55 J/g*^oC.

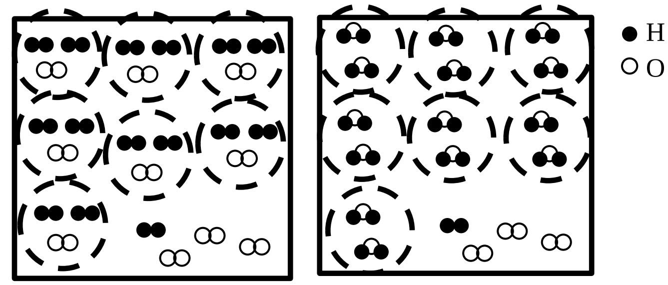
9. A. At 25 ^oC, pure water has a pH of 7.00, corresponding to a $[H^+]$ of 1.0 x 10^{-7} M. At 37 ^oC, the pH drops to 6.80, corresponding to a $[H^+]$ of 1.6 x 10^{-7} M, higher than at 25 ^oC. The H^+ in pure water is produced through autoionization: $H_2O_{(l)} \leftrightarrow H^+_{(aq)} + OH^-_{(aq)}$. Since there is a higher concentration of products at a higher temperature, it can be deduced that the process is endothermic.

10. C. The actual yield of a reaction can never be higher than the theoretical yield, only less than or equal to it.

11. B. For a mixture of gases, the partial pressure of a gas is equal to its mole fraction in the mixture times the total pressure: $P_A = X_A*P_T$. Since the total pressure is the sum of the partial pressures, the partial pressure of F_2 must be 12.2 atm. Therefore the mole fraction of F_2 in the mixture is 12.2/20.0 = 0.61. Since there are 10.0 moles of gas total, the number of moles of F_2 is 0.61 * 10.0 = 6.1 moles.

12. C. If the solution is in contact with solid salt, it must be saturated. After the addition of more water, the solution is still in contact with solid, so is still saturated. The concentration must be the same before and after the addition.

13. B. According to the balanced reaction, 2 molecules of H_2 will react with one molecule of O_2 to produce 2 molecules of H_2O. In the "before" picture to the near right, each circled group of molecules will react to give two water molecules, producing the "after" picture to the far right. Since they must react in pairs, only 14 of the H_2 molecules can react, producing 14 water molecules, and leaving one H_2 and three O_2 molecules unreacted, for a total of 18 molecules.



Before Reaction After Reaction

14. D. Atoms in a molecule are chemically bound to each other. Molecules in a mixture interact physically.

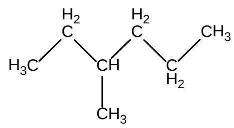
15. C. The large jump in ionization energies between IE_3 and IE_4 indicates the element has three valence electrons. Al is the only choice that has 3 valence electrons.

16. A. Beaker 1 has a higher concentration of H^+ than beaker 2. The only way a weak acid solution can have a higher $[H^+]$ than a strong acid solution is if the weak acid is more concentrated. B cannot be true because by definition the K_a for a weak acid is less than 1, while it is greater than 1 for a strong acid. C may be true, but it is not required to be. D states the opposite of the problem given. E cannot be true because a stronger acid will have a weaker conjugate base.

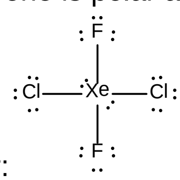
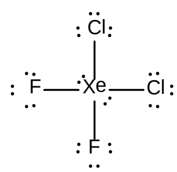
17. E. Two chromium ions go from a +3 oxidation state to a +6, indicating a transfer of 6 electrons total (3 each). Similarly, 6 chlorine atoms go from 0 to -1, showing the same transfer of 6 electrons.

18. E. The threshold frequency for a metal to display the photoelectric effect is the frequency of light corresponding to the binding energy of electrons in the metal. The fact that metal 1 has a higher threshold frequency, requiring higher energy photons to display the effect, indicates it has a higher binding energy. Answer A cannot be true because the photons being used are below the threshold frequency for metal 1. C and D are not true because each photon that hits the metal surface will eject one electron. If the metals are being hit

with light of equal intensity, they will eject an equal number of photons. When an electron is ejected, any energy over the threshold energy is turned into kinetic energy of the electron, or KE = hv – binding energy. When hit with light of the same energy, a higher binding energy will result in electrons with a smaller kinetic energy (slower). Therefore B cannot be true.

19. D. 3-methyl hexane is: 

20. A. The two isomers will have the same shape, molecular weight, and ideal bond angles. However, one is polar and the other is not:

Non-polar:  Polar: 

21. C. Converting each sample to a mass, A is 64 g, B is 96 g, C is 28 g, D is 39 g, and E is 155 g.

22. E. In dilution, $M_1V_1 = M_2V_2$. Since 554 mL of solvent evaporated, V_2 is what is left, 346 mL. Substituting in the given values for M_1 and V_1, it can be determined that M_2 is 0.780 M.

23. D. $1.573 \text{ g } Cu_2S * \frac{1 \text{ mol } Cu_2S}{159.17 \text{ g}} * \frac{4 \text{ mol Cu}}{2 \text{ mol } Cu_2S} * \frac{63.55 \text{ g Cu}}{1 \text{ mol Cu}} = 1.26 \text{ g Cu theoretical yield.}$
Actual yield = 0.632 * theoretical yield = 0.794 g Cu.

24. C. The magnitude of a boiling point elevation is dependent on the concentration of independent solute particles. Since a non-ideal solution does not fully dissociate, dissolving equal moles of NaCl will result in fewer independent particles in the non-ideal solution than in the ideal solution, resulting in a lower particle concentration in the non-ideal solution, and less boiling point elevation, resulting in a lower boiling point.

25. D. q = m*c*ΔT. Since all of the samples are the same mass and absorb the same amount of heat, the one with the smallest c will have the largest ΔT. Of the choices given, this corresponds to Pb.

26. E. Si^- and P are isoelectronic with each other, and C^-, N, and O^+ are isoelectronic with each other. In a given isoelectronic series, the species with the most protons will have the highest ionization energy, P and O^+ in this case. By the periodic trends in ionization energy, we also know N will have a higher IE than P. Since O^+ has a higher IE than N, it must also be higher than P.

27. A. A basic solution is characterized by a higher concentration of OH^- than H_3O^+. A pH of 7.00 is characteristic of a neutral solution at 25 ^oC.

28. C. Pb atoms have 82 protons. If the total mass of the isotope is 208, there are 126 neutrons.

29. D. $\frac{2.4 \text{ mol Y}}{\text{L}*\text{min}} * \frac{5 \text{ moles Z}}{3 \text{ moles Y}} = \frac{4.0 \text{ mol Z}}{\text{L}*\text{min}}$

30. C. The observed net reaction would not contain any intermediates (SO_2). The first reaction must be multiplied by 2 before adding them together, giving reaction C.

31. E. An α-particle is ${}^{4}_{2}\text{He}$. Adding this back into the ${}^{208}_{81}\text{Tl}$ nuclide gives a species with 83 protons and a total mass of 212, or ${}^{212}_{83}\text{Bi}$.

32. E. NO_3^- exhibits resonance, making all three N-O bonds equivalent.

33. B. At equilibrium, 1.25 M * 0.350 L = 0.4375 moles of N_2O_4 have been formed. By the stoichiometry of the reaction, 0.875 moles of NO_2 were used up to form the N_2O_4, leaving 0.675 mole of NO_2. Therefore $[NO_2]$ = 0.675 mol/0.350 L = 1.929 M. K_C for this reaction is equal to $[N_2O_4]/[NO_2]^2 = 1.25/1.929^2 = 0.336$.

34. C. A photon with the largest frequency means a photon with the highest energy. To be *emitted*, the transition must be from a higher energy level to a lower one, eliminating A and B as choices. Given the associated figure, the energy change corresponding to 2→1 is a higher energy transition than 3→2 or 5→4.

35. D. Nickel has 28 protons. 30 neutrons will give the isotope a total mass number of 58. Having only 26 electrons means a charge of +2.

36. E. In a first-order reaction, half-life is constant regardless of the starting amount of material.

37. B. There are 23 electrons in the species listed. Mn^+ would have 24 electrons, eliminating choices C and E. A ground state V atom would have 2 electrons in a 4s orbital, and only 3 electrons in the 3d orbital. A ground state Cr atom has a $4s^13d^5$ valence configuration. Ionization removes the 4s electron first, producing the given electron configuration. This then corresponds to a ground state Cr^+ ion.

38. D. A and B are false; it is possible to have polar bonds and/or lone pairs on a the central atom of a molecule and still have a non-polar molecule. The lone pair of electrons on the N in NH_3 will compress the bond angles from the ideal value of 109.5^o, making C false. A triple bond consists of one sigma and two pi bonds, not three sigma bonds as stated in E.

39. E. Brønsted-Lowry acids are characterized by their ability to donate protons. When a Brønsted-Lowry acid is added to water, some of the protons may be donated to water molecules (B), forming H_3O^+, and increasing the concentration of that species (A). This increase in $[H_3O^+]$ lowers the pH (D). Some of the donated protons (or some of the newly formed H_3O^+) will react with OH^-, decreasing its concentration (C).

40. D. A galvanic cell produces a spontaneous current (refuting B). Electrons will travel from anode to cathode, making A false. The oxidation and reduction species must be physically separated to force the current to go through an external wire, making C false. To balance charge, cations will diffuse toward the cathode, and anions will diffuse toward the anode, making E false.