2014 Academic Challenge Sectional Chemistry Exam Solution Set

1. A. At constant temperature and pressure, the volume of a gas is proportional to the number of moles of gas. According to the balanced reaction:

$$0.750 \text{ L HCl} * \frac{1 \text{ L CHCl}_3}{3 \text{ L HCl}} = 0.250 \text{ L CHCl}_3$$

2. B. An isoelectronic series contains atoms & ions with the exact same number of electrons in the same orbitals. The only way a species can be neutral is if it has the same number of protons as electrons. Therefore for any given series, only one species maybe neutral, the element with an atomic number equal to the number of electrons in the series.

3. E. Energy is inversely proportional to wavelength. Blue light has the shortest wavelength of the colors listed.

4. D. The balanced reaction is: $2CuO_{(s)} + C_{(s)} \rightarrow 2Cu_{(s)} + CO_{2(g)}$. Using molecular weights to convert the given mass to moles, there are 1.26 moles of CuO. Using the stoichiometry of the reaction:

$$1.26 \text{ mol CuO} * \frac{1 \text{ mol CO}_2}{2 \text{ mol CuO}} = 0.630 \text{ mol CO}_2$$

Since 0.63 moles of CO_2 is the theoretical yield, and 0.580 moles is the actual yield, the percent yield is $\frac{0.580 \text{ mol}}{0.63 \text{ mol}} * 100\% = 92.3\%$ yield.

5. D. $3 \text{ mol Ca} * \frac{40.08 \text{ g}}{1 \text{ mol Ca}} + 2 \text{ mol P} * \frac{30.98 \text{ g}}{1 \text{ mol P}} + 8 \text{ mol O} * \frac{16.00 \text{ g}}{1 \text{ mol O}} = 310.2 \text{ g/mol}$

6. B. This is the only reaction in which the oxidation numbers of some elements change.

7. B. $\frac{2.61 \text{ x } 10^{-19} \text{g}}{1000 \text{ atoms}} * \frac{6.022 \text{ x } 10^{23} \text{atoms}}{1 \text{ mole}} = 157 \text{ g/mol}$. This atomic weight corresponds to the element gadolinium, Gd.

8. A. To obtain the reaction three as the net reaction, reaction one must be used as is, while reaction two must be reversed and multiplied by four. The total enthalpy change of the net reaction (ΔH_3) is therefore ΔH_1 + (-4)*ΔH_2 = -1148 kJ + (-4)*115 kJ = -1608 kJ.

9. B. H_2SO_4 and $Ca(OH)_2$ will react in a 1:1 ratio. Therefore:

$$0.03500 \text{ L Ca(OH)}_2 * \frac{0.418 \text{ mol Ca(OH)}_2}{1 \text{ L}} * \frac{1 \text{ mol H}_2\text{SO}_4}{1 \text{ mol Ca(OH)}_2} * \frac{1 \text{ L}}{0.863 \text{ mol H}_2\text{SO}_4} = 0.0170 \text{ L} = 17.0 \text{ mL}$$

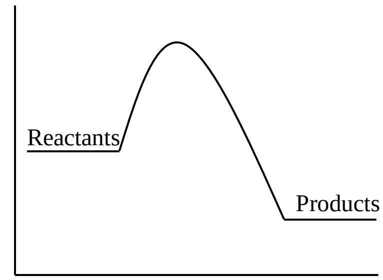
10. B. $60.0 \text{ g O}_2 * \frac{1 \text{ mol O}_2}{32.0 \text{ g}} * \frac{6.022 \text{ x } 10^{23} \text{molecules}}{1 \text{ mole}} = 1.13 \text{ x } 10^{24} \text{ molecules}$

11. C. Gases behave most ideally at high temperature and low pressure, and least ideally at low temperature and high pressure.

12. C. The mass percent of carbon in the compound must be constant regardless of the source of the sample:

$$4.79 \text{ plant sample} * \frac{3.37 \text{ g C in synthetic sample}}{5.39 \text{ g synthetic sample}} = 2.99 \text{ g C in plant sample}$$

13. E. Isoelectronic indicates the same number of total electrons in the same arrangement. Both CO_2 and NO_2^+ will have a central atom doubly-bonded to two terminal atoms, with each terminal atom having two lone pairs.



14. A. A one-step, reversible, exothermic reaction will have the reaction coordinate diagram shown on the right. The activation energy of the forward reaction is the vertical distance from the reactants to the top of the hill. The activation energy of the reverse reaction is the distance from the products to the top of the hill. The exothermic nature of the reaction requires EA_{fwd} to be less than EA_{rev}. It is not required that this obey a first order rate law or be a gas phase reaction (B or D). The dissociation of chlorine gas into chlorine atoms would be an endothermic reaction due to the bond breaking (C). There are no intermediates in a one-step reaction (E).

15. C. At the same temperature, the sample with the highest vapor pressure will be the one with the weakest intermolecular forces. All of the molecules will have Van der Waals forces. B and D are also capable of hydrogen-bonding. A and E will have dipole-dipole interactions. Since C has only Van der Waals forces, it has the weakest overall interactions, and the highest vapor pressure.

16. D. The ideal gas law, PV = nRT, can be rewritten as PV = $\frac{\text{mass}}{\text{MW}}$*RT, where MW is the molecular weight of the gas. Solving this equation for MW, and using the relationship density (d) = mass/V gives: MW = $\frac{\text{dRT}}{\text{P}} = \frac{2.99\frac{\text{g}}{\text{L}}*0.08206\frac{\text{L*atm}}{\text{mol*K}}*298 \text{ K}}{0.500 \text{ atm}} = 146.2 \text{ g/mol}.$

17. D. Multiplying the concentration of each compound by the number of ions in one unit of each compound gives 1.6 M ions in D. A is 1.4 M in ions, B is 1.2 M, and C and E are each 1.5 M.

18. C. I and III each affect the boiling point. III affects where the normal boiling point of pure solvent occurs, while I affects the magnitude of the boiling point elevation. II and IV have no effect. Since only nonelectrolytes are being considered, the identity of the solute does not matter, and the molecular geometry does not have an effect.

19. A. After each half-life, ½ of the sample remains. Thus after 5 half-lives the fractional of sample remaining is $(½)^5 = 0.0313$, or 3.13%

20. E. The central atom in A is sp^3d hybridized, B is sp^3, C is sp^3d^2, D is sp, and E is sp^2.

21. C. Reaction of all of the hydrogen would produce 1.3 moles of ammonia, reaction of all of the nitrogen would produce 2.0 moles of ammonia. Therefore hydrogen is the limiting reagent, and 1.3 moles of ammonia (17.02 g/mol) is the maximum amount that can be produced, corresponding to 23 g.

22. C. The oxidation state of S in this compound is +2.5. In A and E it is +4, in B it is +3, in D it is +6.

23. E. This is the only correctly balanced reaction showing the species specified. A is not balanced. B uses O atoms instead of O_2 gas and does not show the proper product. C does not show the proper product. D uses O atoms instead of O_2 gas.

24. B. These properties are all characteristic of the halogens. The X^- ion being the most stable is enough to rule out any of the other families.

25. D. Accuracy is a measurement of the agreement with an actual value, precision is a measurement of agreement among repeated measurements.

26. A. Since some of the solid dissolved, the original solution was unsaturated. Since not all of the solid dissolved, what was tested must now be saturated.

27. A. The reaction quotient for this reaction is: $\frac{0.935}{2.5*0.0530^2} = 133$. Since Q_P is greater than K_P, the reaction is not at equilibrium, and must shift toward the reactants side to achieve equilibrium (to make $Q_P = K_P$).

28. D. The Lewis structure for this compound consists of a double bond between the nitrogen and the oxygen, indicating a bond order of 2.

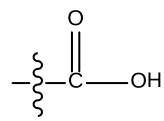
29. D. The molecular weight of this compound is 194 g/mol, and 1 mole contains 96 g of carbon. The mass percent of carbon is therefore 96/194 * 100% = 49.5%.

30. C. For electromagnetic radiation $\lambda = c/v = (2.998 \times 10^8$ m/s)/(165 MHz * 10^6 Hz/1 MHz) = 1.82 m.

31. A. This compound is diphosphorus pentaoxide. B, C, and E are all ionic compounds, whose names do not require numerical prefixes. D (ammonia) would systematically be named trihydrogen nitride.

32. D. The total energy needed is $q = m*c*\Delta T$ = 4.184 J/g*^{o}C * 357 g * (83.0 – 15.0) ^{o}C = 102000 J = 102 kJ

33. B. Only the second molecule is polar. In the third and fourth structures, the square planar shape causes any bond dipoles to cancel out.

34. E. A carboxylic acid is indicated by the functional group: 

35. E. All of the other compounds can be reduced to smaller whole numbers while keeping the same ratio of elements (C would be CH_2O).

36. C. $K = 1.15 \times 10^{-9} = \frac{[H_2]^2}{[CH_4]} = \frac{[H_2]^2}{0.296}$. $[H_2] = 1.84 \times 10^{-5}$ M

37. B. In a weak acid solution, $[H^+]$ = [conjugate base]. In this case, $[H^+] = [ClO_2^-] = 10^{-2.37} = 4.3 \times 10^{-3}$ M

38. B. Two molecules of dimethyl ether cannot hydrogen bond with each other, they do not have any hydrogens capable of H-bonding.

39. D. If $rate_1 = k*[A]_1*[B]_1^2$, $[A]_2 = 2[A]_1$, and $[B]_2 = 3[B]_1$, then $rate_2 = k*(2[A]_1)*(3[B]_1)^2 = 2*k*[A]_1*(9[B]_1^2) = 18*k*[A]_1*[B]_1^2 = 18*rate_1$.

40. D. The full electron configuration of a ground state Si atom is $1s^2 2s^2 2p^6 3s^2 3p^2$, indicating 8 electrons total in p-orbitals.