CHEM 103
R&R—extra Final Exam practice :)
27 June 2024
Adapted from an undated document

Note that the ideal gas constant R = 62.36 L torr mol^{-1} K^{-1} when using torr instead of atm.

1. Write the full and net ionic equations for each of the processes below.

a. Silver nitrate + sodium oxalate

$2AgNO_3(aq) + Na_2C_2O_4(aq) \longrightarrow Ag_2C_2O_4(s) + 2NaNO_3(aq)$

net: $2Ag^+(aq) + C_2O_4^{2-}(aq) \longrightarrow Ag_2C_2O_4(s)$

b. Hydrobromic acid + ammonia

$HBr(aq) + NH_3(aq) \longrightarrow NH_4^+(aq) + Br^-(aq)$

net: $H_3O^+(aq) + NH_3(aq) \longrightarrow H_2O(l) + NH_4^+(aq)$

c. Iron(II) nitrate + sodium hydroxide

$Fe(NO_3)_2(aq) + 2NaOH(aq) \longrightarrow Fe(OH)_2(s) + 2NaNO_3(aq)$

net: $Fe^{2+}(aq) + 2OH^-(aq) \longrightarrow Fe(OH)_2(s)$

d. Acetic acid + barium hydroxide

$2CH_3CO_2H(aq) + Ba(OH)_2(aq) \longrightarrow Ba(CH_3CO_2)_2(aq) + 2H_2O(l)$

net: $CH_3CO_2H(aq) + OH^-(aq) \longrightarrow CH_3CO_2^-(aq) + H_2O(l)$

2.

a. Write the full ground state electron configurations of S, K, Ti, and Sn.

S: $1s^2 2s^2 2p^6 3s^2 3p^4$

K: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$

Ti: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 4s^2$

Sn: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^2$

b. Write the noble gas notation electron configurations for Ni, Ge, Cs, and Br.

Ni: $[Ar] 3d^8 4s^2$

Ge: $[Ar] 3d^{10} 4s^2 4p^2$

Cs: $[Xe] 6s^1$

Br: $[Ar] 3d^{10} 4s^2 4p^5$

3. An electron in a hydrogen atom is excited from the ground state to the n = 4 state. Comment on the correctness of following statements.

a. n = 4 is the first excited state. False.

Starts out in $n=1$, so $n=2$ is the first excited state.

b. It takes more energy to ionize (remove) the electron from n = 4 than from the ground state.

False. The excited state has already had energy put into it, so less energy is required to ionize the $n=4$ electron.

c. The wavelength of light emitted when the electron drops from n = 4 to n = 1 is longer than that from n = 4 to n = 2.

False. $\Delta E(n=4\rightarrow1) > \Delta E(n=4\rightarrow2)$, so the first photon has a greater frequency, and accordingly a smaller wavelength.

d. The wavelength the electron absorbs in going from n = 1 to n = 4 is the same as that emitted when it goes from n = 4 to n = 1.

True. These are reverse processes.

4. Below is a list of successive ionization energies, expressed in kJ mol^{-1}, for a period 3 element. Identify the element and explain how you came to that conclusion.

I_1 = 1012; I_2 = 1900; I_3 = 2910; I_4 = 4960; I_5 = 6270; I_6 = 22 200

Element is in group 5 ⟸ big jump (between I_5 and I_6)

Element is phosphorus.

5. Arrange these compounds in order of increasing boiling point. Explain your reasoning.

a. CH_4 b. CH_3CH_3 c. CH_3CH_2Cl d. CH_3CH_2OH

$CH_4 < CH_3CH_3 < CH_3CH_2Cl < CH_3CH_2OH$

- ($CH_4 < CH_3CH_3$): smaller, less polarizable for LDFs
- ($CH_3CH_3 < CH_3CH_2Cl$): chloroethane has a polar bond, enabling dipole-induced dipole interactions
- ($CH_3CH_2Cl < CH_3CH_2OH$): hydrogen bonding is the strongest!

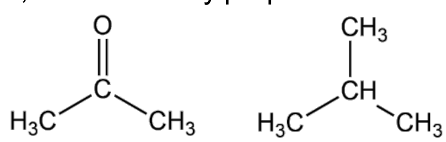
6. Which type of intermolecular force accounts for each of these differences?

a. CH_3OH boils at 65 °C; CH_3SH boils at 6 °C. H-bonding vs. dipole-dipole

b. Xe is a liquid at atmospheric pressure and 120 K, while Ar is a gas under the same conditions. LDFs (larger is more polarizable)

c. Kr, atomic weight 84 g/mol, boils at 120.9 K, while Cl_2, molecular weight 71 g/mol, boils at 238 K. LDFs (larger is more polarizable)

d. Acetone boils at 56 °C, while 2-methylpropane boils at -12 °C.



acetone 2-methylpropane

dipole-dipole is stronger than LDFs

7. For each of the following reactions, determine whether it is a redox reaction. If it is a redox reaction, identify which element is oxidized and which is reduced; provide before-and-after oxidation states.

a. $\overset{+0}{Sn}$ (s) + 4 $\overset{+1}{H}\overset{+5}{N}\overset{-2}{O_3}$ (aq) → $\overset{+4}{Sn}\overset{-2}{O_2}$ (s) + 4 $\overset{+4}{N}\overset{-2}{O_2}$ (g) + 2 $\overset{+1}{H_2}\overset{-2}{O}$ (l) REDOX

(Sn: ox; N: red)

b. $\overset{+1}{Hg_2}(\overset{+5}{N}\overset{-2}{O_3})_2$ (aq) + 2 $\overset{+1}{K}\overset{-1}{Br}$ (aq) → $\overset{+1}{Hg_2}\overset{-1}{Br_2}$ (s) + 2 $\overset{+1}{K}\overset{+5}{N}\overset{-2}{O_3}$ (aq) precipitation

c. 4 $\overset{+0}{Al}$ (s) + 3 $\overset{+0}{O_2}$ (g) → 2 $\overset{+3}{Al_2}\overset{-2}{O_3}$ (s) REDOX

(Al: ox; O: red)

8. Compute the ΔH for the following reactions using bond enthalpies:

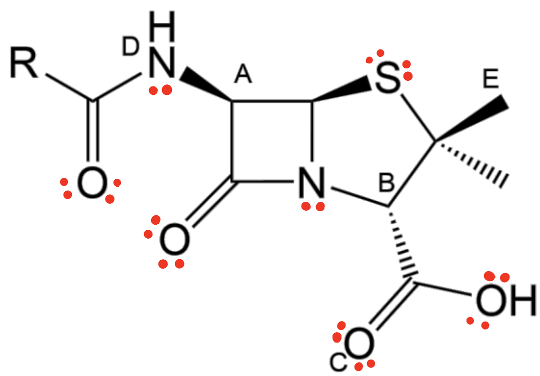
a. 1 H_2 (g) + 1 Br_2 (g) → 2 HBr (g)

$\Delta H = (BDE[H-H] + BDE[Br-Br]) - 2BDE[HBr] = (436\frac{kJ}{mol} + 193\frac{kJ}{mol}) - 2\cdot 366\frac{kJ}{mol}$
$= -103\ kJ/mol$

b. 2 H_2O_2 (g) → 2 H_2O (g) + 1 O_2 (g)

$\Delta H = (2\cdot BDE[O-O] + 4\cdot BDE[O-H]) - (4\cdot BDE[O-H] + BDE[O=O]) = 2\cdot 180\frac{kJ}{mol} - 498\frac{kJ}{mol} = -138\frac{kJ}{mol}$

9. Below is the structure of the penicillin class of antibiotics (R represents a variable group).



a. Fill in all lone pairs in the above molecule. Remember the octet rule!

b. What is the hybridization of the atoms labeled A-E?

A: sp^3 B: sp^3 C: sp^2 D: sp^3 E: sp^3

c. What is the electron geometry at the atoms labeled B-E?

B: tetrahedral C: trig. planar D: tetrahedral E: tetrahedral

d. Discuss one way penicillin can interact with the aqueous environment of the body using IMFs.

There is a fair number of hydrogen bonding donors (the carboxyl -OH and the amide N-H) and acceptors (the lone pairs on O and N atoms). These can hydrogen bond with the water in the body.

If the carboxylic acid group gets deprotonated, then the resulting negative charge would result in an even stronger ion-dipole interaction.

10. What mass of sodium acetate can be obtained from mixing 15.0 g $NaHCO_3$ with 150. mL of 0.100 M acetic acid?

$$15.0\,g\ NaHCO_3 \cdot \frac{mol\ NaHCO_3}{84.006\,g\ NaHCO_3} = 0.1785\ mol\ NaHCO_3$$

$$(150.\ mL)(0.100\ M\ CH_3CO_2H) = 15.0\ mmol\ CH_3CO_2H$$ ← limiting reactant

$$15.0 \times 10^{-3}\ mol\ CH_3CO_2H \cdot \frac{mol\ NaCH_3CO_2}{mol\ CH_3CO_2H} \cdot \frac{82.04\,g\ NaCH_3CO_2}{mol\ NaCH_3CO_2} = 1.23\,g\ NaCH_3CO_2$$

11. Formic acid, HCOOH, is a monoprotic weak acid.

a. Write the full and net ionic equations for the reaction of aqueous formic acid and aqueous potassium hydroxide.

total: $HCO_2H\,(aq) + K^+(aq) + OH^-(aq) \rightarrow HCO_2^-\,(aq) + K^+(aq) + H_2O\,(l)$

net: $HCO_2H\,(aq) + OH^-(aq) \rightarrow HCO_2^-\,(aq) + H_2O\,(l)$

b. If you combine 60.0g formic acid and 60.0g potassium hydroxide, how much water (in grams) will you produce? Which is the limiting reactant?

$$60.0\,g\ HCO_2H \cdot \frac{mol\ HCO_2H}{46.03\,g\ HCO_2H} = 1.303\ mol\ HCO_2H$$

$$60.0\,g\ KOH \cdot \frac{mol\ KOH}{56.11\,g\ KOH} = 1.069\ mol\ KOH$$ ← limiting reactant

$$1.069\ mol\ KOH \cdot \frac{mol\ H_2O}{mol\ KOH} \cdot \frac{18.02\,g\ H_2O}{mol\ H_2O} = 19.3\,g\ H_2O$$

12. Sweat cools the body because evaporation is an endothermic process:

$$H_2O\ (l) \rightarrow H_2O\ (g) \qquad \Delta H^\circ_{rxn} = +\ 44.01\ kJ$$

Estimate the mass of water that must evaporate from the skin to cool the body by 0.50 °C. Assume a body mass of 95 kg and that the specific heat capacity of the body is 4.0 J $(g{\cdot}K)^{-1}$.

$$95\,kg \cdot \frac{4.0\,J}{g\cdot K} \cdot (0.50\,K) \cdot \frac{mol\ H_2O}{44.01\,kJ} \cdot \frac{18.02\,g\ H_2O}{mol\ H_2O} = 78\,g$$

13. Lakes that have been acidified by acid rain (HNO_3 and H_2SO_4) can be neutralized by a process called liming, in which limestone ($CaCO_3$) is added to the acidified water. What mass of limestone (in kg) would be required to completely neutralize a 15.2 billion-liter lake that is 1.8×10^{-5} M in H_2SO_4 and 8.7×10^{-6} M in HNO_3?

$H_2SO_4 + CaCO_3 \longrightarrow CaSO_4 + H_2O + CO_2$; $2HNO_3 + CaCO_3 \longrightarrow Ca(NO_3)_2 + H_2O + CO_2$

$$(1.8\times10^{-5}\ M\ H_2SO_4)(15.2\times10^{9}\ L)\cdot\frac{mol\ CaCO_3}{mol\ H_2SO_4}\cdot\frac{100.09\ g\ CaCO_3}{mol\ CaCO_3} = 27385\ kg\ CaCO_3$$

$$(8.7\times10^{-6}\ M\ HNO_3)(15.2\times10^{9}\ L)\cdot\frac{mol\ CaCO_3}{2\ mol\ HNO_3}\cdot\frac{100.09\ g\ CaCO_3}{mol\ CaCO_3} = 6618\ kg\ CaCO_3$$

Need 34000 kg $CaCO_3$

14. Find the mass of barium metal (in grams) that must react with oxygen gas to produce enough barium oxide to prepare 1.0 L of a 0.10 M solution of OH^-.

$Ba(s) + \frac{1}{2}O_2(g) + H_2O(l) \longrightarrow Ba(OH)_2(aq)$

$$(1.0\ L)(0.10\ M\ OH^-)\cdot\frac{mol\ Ba}{2\ mol\ OH^-}\cdot\frac{137.33\ g\ Ba}{mol\ Ba} = 6.9\ g\ Ba$$

15. CaO (s) reacts with water to form $Ca(OH)_2$ (aq). If 6.50 g CaO is combined with 99.70 g H_2O in a coffee cup calorimeter, the temperature of the resulting solution increases from 21.7 °C to 43.1 °C. Calculate the enthalpy change for the reaction per mole of CaO. Assume that the specific heat capacity of the solution is 4.18 J (g·K)$^{-1}$.

$CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(aq)$

$$q = mC_p\Delta T = (6.50\ g + 99.70\ g)\left(4.18\ \frac{J}{g\cdot K}\right)(21.4\ K) = 9.50\ kJ$$

← gained by solution, so heat is given off by solution: $\Delta H < 0$

$$\Delta H = -9.50\ kJ\cdot\frac{1}{6.50\ g\ CaO}\cdot\frac{56.08\ g\ CaO}{mol\ CaO} = -82.0\ \frac{kJ}{mol}$$

16. If you put 120 volts of electricity through a pickle, the pickle will smoke and start glowing orange-yellow (or so I hear). The light is emitted because sodium ions in the pickle become excited; their return to the ground state results in light emission.

a. The wavelength that is emitted is 589 nm. Calculate its frequency.

$$\nu = \frac{c}{\lambda} = \frac{3.00\times10^{8}\ m\cdot s^{-1}}{589\times10^{-9}\ m} = 5.09\times10^{14}\ Hz$$

b. What is the energy of 0.10 mol of these photons?

$$E = nh\nu = (0.10\times6.022\times10^{23})(6.626\times10^{-34}\ J\cdot s)(5.09\times10^{14}\ s^{-1}) = 20.\ kJ$$

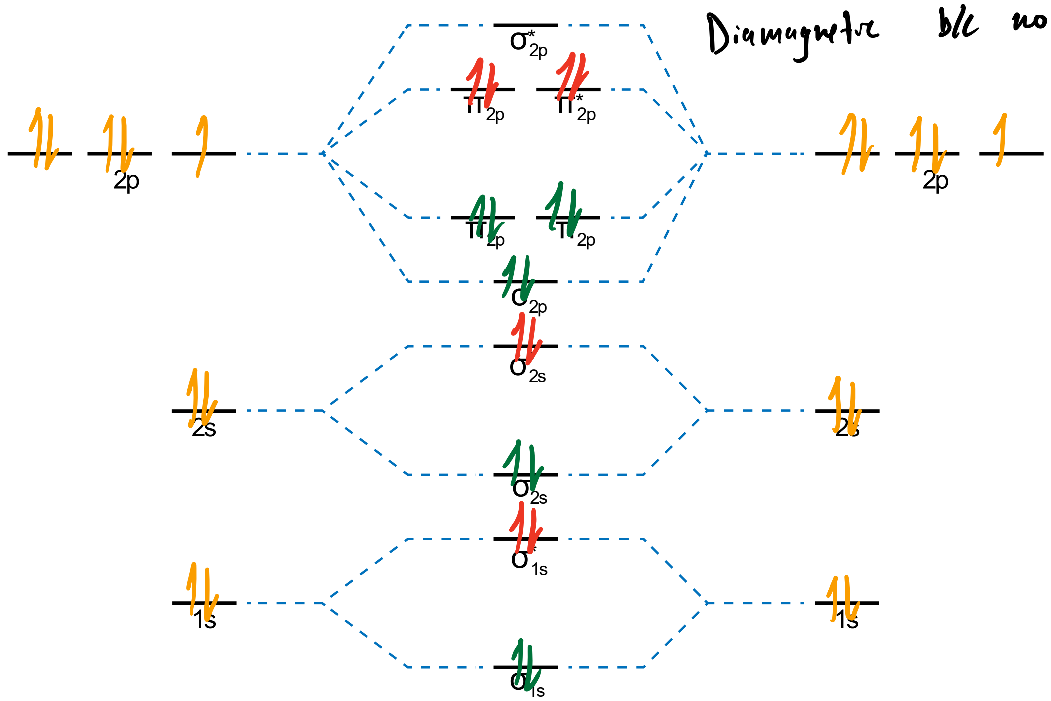
c. Calculate the energy gap between the excited and ground states for the sodium ion.

$$\Delta E = h\nu = (6.626\times10^{-34}\ J\cdot s)(5.09\times10^{14}\ s^{-1}) = 3.37\times10^{-19}\ J$$

17. Fill in the molecular orbital diagram for F_2. Give the bond order and identify whether F_2 is diamagnetic or paramagnetic.

bond order $= \frac{1}{2}(10-8) = 1.$

Diamagnetic b/c no unpaired e^-s.



(Diagram sourced from https://ch301.cm.utexas.edu/imfs/#mo/mo-theory-all.php)

18. A gaseous compound containing hydrogen and carbon is decomposed and found to contain 82.66% carbon and 17.34% hydrogen by mass. The mass of 158 mL of the gas, measured at 556 torr and 25 °C, was 0.275 g. What is the molecular formula of the compound?

$$n = \frac{PV}{RT} = \frac{(556 \text{ torr})(0.158 \text{ L})}{(62.36 \frac{\text{torr}\cdot\text{L}}{\text{mol}\cdot\text{K}})(298.15 \text{ K})} = 0.004724 \text{ mol gas}$$

1:4 ratio

$$0.275 \text{ g gas} \cdot \frac{0.8266 \text{ g C}}{\text{g gas}} \cdot \frac{\text{mol C}}{12.01 \text{ g C}} = 0.01893 \text{ mol C}$$

1:10 ratio

$$0.275 \text{ g gas} \cdot \frac{0.1734 \text{ g H}}{\text{g gas}} \cdot \frac{\text{mol H}}{1.008 \text{ g H}} = 0.0473 \text{ mol H}$$

molecular formula is C_4H_{10}.

Can check this. C_4H_{10} has molar mass of 58.12 $g \cdot mol^{-1}$.

We have 0.004724 mol, so we expect a sample mass of

$$(0.004724 \text{ mol})(58.12 \text{ g}\cdot\text{mol}^{-1}) = 0.2745 \text{ g}$$ ☺

GOOD LUCK!