7 1 Andy
3 2 Andy
4 3 Lou
4 4 Andrei
16 5 Simmy
16 6 Calvin
9 7 Kaiyan Lu
10 8 ~~Andrei~~ Benny
9 9 ~~Andrei~~
10 10 Lei
8 11 Lei
4 12/13 Calvin

Chemistry Department of the City College of New York
Chemistry 10301 BB, BB2, CC, CC2, L, L2
Final Examination **December 19, 2000**
Name (Last Name First): _____
I.D. Number: _____

Circle your Instructor: **Lazaridis** **Radel** **Simms**

TOTAL _____

Note: Write your name on each page and work out all the numerical problems to the correct number of significant figures.

Useful Data:
1 m = 10^2 cm = 10^9 nm = 10^{12} pm
The Avogadro number is 6.022×10^{23}
Gas constant, R = 0.0821 L atm/mol K
Speed of electromagnetic radiation = 2.998×10^8 m/s
Planck's constant = 6.626×10^{-34} J s

1. Cortisone (a hormone composed of carbon, hydrogen, and oxygen) is found to be 70.00% C, 7.83% H, and 22.17% O by mass. The molar masses of carbon, hydrogen, and oxygen are 12.01 g/mol, 1.008 g/mol, and 16.00 g/mol, respectively.

$C_{21}H_{28}O_5$

(4) a. Determine the empirical formula of the hormone.

C: $70.00\,g \times \frac{1\ mol\ C\ atom}{12.01\,g} = \frac{5.829\ mol}{1.386} = 4.21 \times 5 = 21$ (①, ①, ③)

H: $7.83\,g \times \frac{1\ mol\ H\ atom}{1.008\,g} = \frac{7.768\ mol}{1.386} = 5.60 \times 5 = 28$

O: $22.17\,g \times \frac{1\ mol\ O\ atom}{16.00\,g} = \frac{1.386\ mol}{1.386} = 1.00 \times 5 = 5$

(3) b. The molar mass of the hormone is 360.5 g/mol. Determine the molecular formula of the hormone.

$$C = \frac{\text{molecular mass}}{\text{Empirical mass}} = \frac{360.5\ g/mol}{360.4\ g/mol} = 1$$

$$\frac{360.5\ g\ comp}{1\ mol\ comp} \times \frac{70.00\ g\ C}{100\ g\ comp} \times \frac{1\ mol\ C}{12.01\ g\ C} = 21\ mol\ C / 1\ mol\ comp$$

$C_{21}H_{28}O_5$

(3) 2. Calculate the molarity of a phosphoric acid solution if 36.25 mL of 0.1256 M sodium hydroxide neutralizes a 50.00-mL sample of the acid. The equation for the reaction of phosphoric acid and sodium hydroxide is

$$H_3PO_4(aq) + 3NaOH(aq) \longrightarrow Na_3PO_4(aq) + 3H_2O(l)$$

NaOH : $36.25\,mL \times \frac{1\,L}{1000\,mL} = 0.03625\,L$

H_3PO_4 : $50.00\,mL \times \frac{1\,L}{1000\,mL} = 0.05000\,L$

$0.1256\,M \times 0.03625\,L = 0.004553\,mol\ NaOH$

$0.004553\,mol\ NaOH \times \frac{1\,mol\ H_3PO_4}{3\,mol\ NaOH} = 0.001518\,mol\ H_3PO_4$

$\frac{0.001518\,mol}{0.05000\,L} = 0.03036$

H_3PO_4

(4) 3. A 2.55×10^5-mL sample of butane gas at 150°C and 1665 torr is burned with an excess of oxygen:

$$2C_4H_{10}(g) + 13O_2(g) \longrightarrow 8CO_2(g) + 10H_2O(g)$$

Calculate the pressure of carbon dioxide in torr if the reaction products were collected in a 4000.0-L vessel at 15°C.

① For butane (C_4H_{10}):

$P = 1665\,\cancel{torr} \times \frac{1\,atm}{760\,\cancel{torr}} = 2.191\,atm$ $\quad T = 150^\circ C = 423\,K$

$V = 2.55 \times 10^5\,\cancel{mL} \times \frac{1\,L}{10^3\,\cancel{mL}} = 2.55 \times 10^2\,L$

$PV = nRT \Rightarrow (2.191\,atm)(2.55 \times 10^2\,L) = n_{C_4H_{10}} \times 0.0821\,L\,atm/mol\,K \times 423\,K$

$n_{C_4H_{10}} = 16.1\,mol$

(4) 4. A typical microwave oven uses radiation with a 12.2-cm wavelength. When a sample of water is irradiated with 2.00×10^5 moles of microwave photons, its temperature rises from 22.0°C to 99.8°C. Calculate the mass of the water sample in grams. The specific heat of water is 4.2 J/g °C. **Hint:** First calculate the energy of one microwave photon.

② $16.1\,mol\,\cancel{C_4H_{10}} \times \frac{8\,mol\,CO_2}{2\,mol\,\cancel{C_4H_{10}}} = 64.4\,mol\,CO_2$

) For CO_2:

$= 15^\circ C = 288\,K$

$PV = nRT$

$\times 4000.0\,L =$

$64.4\,mol \times 0.0821\,L\,atm/mol\,K$

$288\,K$

$= 0.381\,atm$

$= 0.381\,\cancel{atm} \times \frac{760\,torr}{1\,\cancel{atm}}$

$= 290\,torr$

$q = mc\Delta T$

$\Delta T = 99.8^\circ C - 22.0^\circ C = 77.8^\circ C$

photons : $2.00 \times 10^5\,\cancel{mol} \times \frac{6.022 \times 10^{23}\,photon}{1\,\cancel{mol}} = 1.20 \times 10^{29}\,photon$ ①

$E = \frac{hc}{\lambda}$

$E = \frac{(6.626 \times 10^{-34}\,J\cdot\cancel{s})(2.998 \times 10^8\,\cancel{m/s})}{(12.2\,\cancel{cm} \times 1\,\cancel{m}/100\,\cancel{cm})} = 1.63 \times 10^{-24}\,J/photon$ ①

$q = E = 1.63 \times 10^{-24}\,J \times 1.20 \times 10^{29}\,\cancel{photon} = 1.96 \times 10^5\,J$ ①

$m = \frac{q}{c\Delta t} = \frac{1.96 \times 10^5\,J}{(4.2\,J/g^\circ C)(77.8^\circ C)}$ ④

5. Combustion of trinitrotoluene (TNT) produces nitrogen, carbon dioxide, and water vapor:

$$4C_7H_5N_3O_6(g) + 21O_2(g) \longrightarrow 6N_2(g) + 28CO_2(g) + 10H_2O(g)$$

$$\Delta H° = -1.32 \times 10^4 \text{ kJ}$$

(3) a. During the **constant pressure** combustion of 4 moles of TNT, 1.4×10^3 kJ of work is done by the reacting system on its surroundings. What is the value (be sure to include sign) of q, w, and ΔE for the reaction?

$W = -1.4 \times 10^3$ kJ

$q_p = \Delta H° = -1.32 \times 10^4$ kJ

$\Delta E = q + w = -1.32 \times 10^4 \text{ kJ} - 1.4 \times 10^3 \text{ kJ}$

$\Delta E = -1.46 \times 10^4$ kJ

$\approx -1.5 \times 10^4$ kJ

(4) b. How many moles of CO_2 are produced during the reaction that occurs when 600.0 g of TNT is mixed with 550.0 g of O_2? The molar masses of TNT and O_2 are 227.13 g/mol and 32.00 g/mol, respectively.

(+5) $600 \text{ g TNT} \times \frac{1 \text{ mol}}{227.13 \text{ g}} = 2.642 \text{ mol of TNT}$

$550.0 \text{ g } O_2 \times \frac{1 \text{ mol}}{32.00 \text{ g } O_2} = 17.19 \text{ mol of } O_2$

(+1) $2.642 \text{ mol TNT} \times \frac{21 \text{ mol } O_2}{4 \text{ mol TNT}} = 13.87 \text{ mol } O_2$ ∴ TNT is limiting

(+2) $2.642 \text{ mol TNT} \times \frac{28 \text{ mol } CO_2}{4 \text{ mol TNT}} = 18.49 \text{ mol } CO_2$

(3) c. The above reaction in Part b produced 320.0 g of CO_2. Calculate the percent yield of CO_2. The molar mass of CO_2 is 44.01 g/mol.

$18.49 \text{ mol } CO_2 \times \frac{44.01 \text{ g}}{1 \text{ mol } CO_2} = 813.7 \text{ g } CO_2$ theoretical yield

$$\% \text{ yield} = \frac{\text{Actual}}{\text{Theoretical}} \times 100\% \quad \frac{320.0 \text{ g}}{813.7 \text{ g}} \times 100\% = 39.3\%$$

(3) d. How many kilojoules of heat will be released during the reaction in Part b?

$2.642 \text{ mol TNT} \times \frac{1.32 \times 10^4 \text{ kJ}}{4 \text{ mol TNT}} = 8.719 \times 10^3 \text{ kJ}$ evolved

Question 5 Continued

(3) e. The molar enthalpies of formation of $CO_2(g)$ and $H_2O(g)$ are −393.5 kJ/mol and −241.8 kJ/mol, respectively. Calculate the molar enthalpy of formation of TNT in kJ/mol. $\Delta H^\circ = [nH_{f_{N_2}} + nH_{f_{CO_2}} + nH_{f_{H_2O}}] - [nH_{f_{TNT}} + nH_{f_{O_2}}]$

$-1.32\times10^4\,kJ = (28\times -393.5\,kJ) + (10\times -241.8\,kJ) - 4H_f$

$-1.32\times10^4\,kJ = -11018\,kJ - 2418\,kJ - 4H_f$

$4H_f = -11018\,kJ - 2418\,kJ + 1.32\times10^4\,kJ$

$4H_f = -236\,kJ$

$H_f = -236\,kJ/4\,mol = -59\,kJ/mol$

6. (2) a. Is the wavelength of the photon absorbed by the transition of a hydrogen electron from n = 1 to n = 3 longer than, shorter than, or equal to the ~~frequency~~ of the photon absorbed by the transition n = 3 to n = 5?

shorter

(2) b. Write the **abbreviated** ground-state electron configuration of astatine (atomic number 85).

$[Xe]\,6s^2\,4f^{14}\,5d^{10}\,6p^5$

(2) c. Is the cadmium(II) ion, Cd^{2+}, paramagnetic or is it diamagnetic? (The atomic number of cadmium is 48)

diamagnetic

(2) d. Circle the electron that is least tightly bound to its nucleus:

3s electron of chlorine

(3d electron of chlorine)

3s electron of bromine

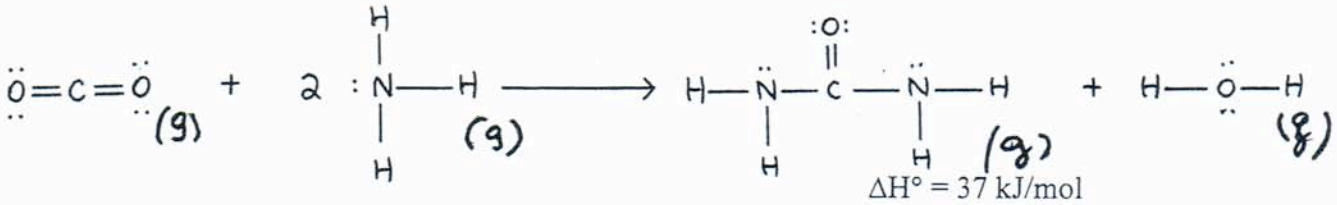
(2) e. Circle the species with the largest ionic radius: N (P^{3-}) S^{2-}

(2) f. Circle the species with the largest ionization energy: (Mg^{2+}) Sr Cs

(2) g. Circle the most electronegative element: Se (Br) Bi

(2) h. Circle the element with the most metallic character: Al Cl (Rb)

7. Urea, $CO(NH_2)_2$, is used as a fertilizer and is made by the reaction of carbon dioxide and ammonia:



$\Delta H° = 37$ kJ/mol

(3) a. Given the following information:

Bond	Bond Energy (kJ/mol)
C = O	802
N—H	391
O—H	463

Calculate the C—N bond energy in kJ/mol.

$\Delta H° = -2(H-O) + -2(C-N) + 2(N-H) + (C=O)$

$37kJ = -2(463) - 2x + 2(391) + (802)$

$37 = -926 - 2x + 782 + 802$

$37 = 658 - 2x \quad \therefore -621 = -2x \quad x = +310.5$

(2) b. Would you expect your answer from Part a to be greater than, smaller than, or equal to the C≡N bond energy? smaller

(4) c. Calculate the **total volume** of CO_2 and NH_3 at 200.0 atm and 450°C that is needed to produce 2.50×10^3 g of urea. The molar mass of urea is 60.06 g/mol.

$2.50 \times 10^3 g \times \frac{1 mol}{60.06 g} = 4.16 \times 10^1 mol\ urea$

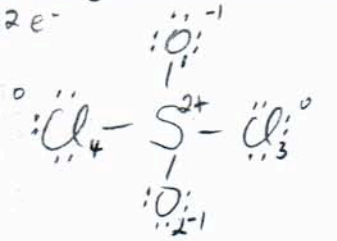
$T = 450°C + 273 = 723 K$

$4.16 \times 10^1 mol\ urea \times \frac{3 mol\ gases}{1 mol\ urea} = 125$

$V = \frac{nRT}{P} = \frac{(125)(0.0821)(723)}{200} = 37.1 L$

8. (3) a. Draw the Lewis structure for SO_2Cl_2 that satisfies the octet rule. Make sure to indicate the formal charge on each atom. **Hint:** Sulfur is the central atom.

$6 + 12 + 14 = 32\ e^-$

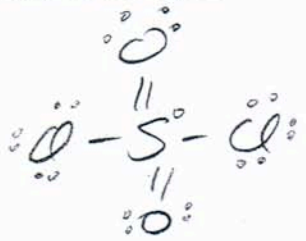


$O_1 \& O_2 = 6 - \frac{1}{2}(2) - 6 = -1$ each

$Cl_3 \& Cl_4 = 7 - \frac{1}{2}(2) - 6 = 0$ each

$S = 6 - \frac{1}{2}(8) = +2$

(3) b. Write the resonance structure of SO_2Cl_2 that has zero formal charge on each atom.



$S = 6 - \frac{1}{2}(12) = 0$

$O_{1,2} = 6 - 4 - \frac{1}{2}(4) = 0$

$Cl_{3,4} = 7 - 6 - \frac{1}{2}(2) = 0$

(4) c. Indicate the geometry (linear, trigonal planar, tetrahedral, etc.) and the approximate bond angle in the following molecule:

	Geometry	Approximate bond angle
$SnCl_2$	Bent	$<120°$

9. $Br_2(l)$ undergoes both oxidation and reduction to form $BrO_3^-(aq)$ and $Br^-(aq)$ in an acidic medium:

$Br_2(l) \longrightarrow BrO_3^-(aq) + Br^-(aq)$ **(incomplete and unbalanced)**

(3) a. What is the oxidation number of bromine in

Br_2?	0
BrO_3^-?	+5
Br^-?	−1

$Br_2 \longrightarrow BrO_3^-$ (0 → +5)

$Br_2 \longrightarrow Br^-$

b. Use the method of half-reactions to find the oxidation and reduction half-reactions and the net ionic equation.

(2) Oxidation: $6H_2O + Br_2 \longrightarrow 2BrO_3^- + 10e^- + 12H^+$

(2) Reduction: $(2e^- + Br_2 \longrightarrow 2Br^-) \times 5$

(2) Net ionic: $6Br_2 + 6H_2O \longrightarrow 10Br^- + 2BrO_3^- + 12H^+$ → ok to reduce

$6H_2O + Br_2 \longrightarrow 2BrO_3^- + 10e^- + 12H^+$

$(2e^- + Br_2 \longrightarrow 2Br^-) \times 5$

$10e^- + 5Br_2 \longrightarrow 10Br^-$

$6H_2O + Br_2 \longrightarrow 2BrO_3^- + 10e^- + 12H^+$

$10e^- + 5Br_2 \longrightarrow 10Br^-$ (× 6)

$6Br_2 + 6H_2O \longrightarrow 10Br^- + 2BrO_3^- + 12H^+$

OR (3) (3) (5) (4) (6)

(2)

10. The following data are given for the element chromium:

Molar mass = 51.996 g/mol

Mass of the unit cell = 1.727×10^{-22} g

Volume of the unit cell = 2.400×10^{7} pm^3

$\frac{51.9996\ g}{1\ mol} \times \frac{1\ mol}{6.022 \times 10^{23}\ atoms} = 8.635 \times 10^{-23}$ g/atom

$\frac{1.727 \times 10^{-22}\ g}{1\ unit\ cell} \times \frac{1\ atom}{8.635 \times 10^{-23}\ g} = 2$ atoms/unit cell

(3) a. Calculate the number of atoms present in one unit cell and identify the type of cubic lattice formed by chromium.

$1.727 \times 10^{-22}\ g \times \frac{1\ mol}{51.996\ g} = 3.321 \times 10^{-24}\ mol$

$3.321 \times 10^{-24}\ mol \times \frac{6.022 \times 10^{23}\ atom}{1\ mol} = 1.999 \approx 2$ (1) BCC

Body centered

(3) b. Calculate the density of chromium in g/cm^3.

1.5 $V = 2.400 \times 10^{7}\ pm^3 \times \frac{10^{-36}\ m^3}{1\ pm^3} \times \frac{10^{6}\ cm^3}{1\ m^3} = 2.4^{20} \times 10^{-20}$ cm

$2.400 \times 10^{7}\ pm^3 \times \left(\frac{10^{2}\ cm}{10^{12}\ pm}\right)^3 =$ ↑

1.5 $d = \frac{m}{V} = \frac{1.727 \times 10^{-22} g}{2.400 \times 10^{-23} cm^3} = 7.196\ g/cm^3$

(4) c. Calculate the volume of a chromium atom in cubic picometers.

$Vol_{unit\ cell} = e^3$

$e = \frac{4r}{\sqrt{3}}$

$Vol_{atom} = \frac{4}{3}\pi r^3$

$E = \frac{4r}{\sqrt{3}}$

$\frac{\sqrt{3}E}{4} = r$

$V = E^3$

$\sqrt[3]{V} = E$

$V = \frac{4}{3}\pi r^3$

(1) $E = \sqrt[3]{2.400 \times 10^{7}\ pm^3}$

$= 288.4$ pm

(2) $r = \frac{\sqrt{3}}{4}(288.4\ pm) = 124.9$ pm

(3) $V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi \left(124.9\ pm\right)^3$

$= 8.162 \times 10^{6}\ pm^3$

For face-centered cubic lattice: $e = 2\sqrt{2}r$

" simple cubic lattice: $e = 2r$

11. (2) a. What is the formula of iron(II) phosphate? $Fe_3(PO_4)_2$

(2) b. What is the name of P_4S_3? ~~Phosphorous Trisulfide~~ tetraphosphorus trisulfide

(4) c. Write a balanced equation for each of the following reactions. **Note:** It is not necessary to indicate the physical state of each substance.

I. Chlorine with water.

$$Cl_2 + H_2O \rightleftharpoons \underbrace{H^+ + Cl^-}_{\text{or } HCl} + HClO \text{ or } HOCl$$

II. Nitrogen with hydrogen.

$$N_2 + 3H_2 \rightarrow 2NH_3$$

Professors Lazaridis and Radel's students should do question 12 and professor Simms's students should do question 13

(4) 12. Consider the substances H_2O, CO_2, and SO_2.

Which substance has the highest boiling point? H_2O

Which substance has the lowest boiling point? CO_2

(4) 13. Consider the ionic compounds RbBr, $CaCl_2$, and $SrCl_2$.

Which compound has the highest lattice energy? $CaCl_2$

Which compound has the lowest lattice energy? RbBr