CHM1311 B: Principles of Chemistry

Prof. N. Goto
Assignment #3
Due Oct 13th, at the beginning of class

Assignments can be submitted individually, or by groups of up to 4 students.

1) Name: ______________ **Student ID:** ______________

2) Name: ______________ **Student ID:** ______________

3) Name: ______________ **Student ID:** ______________

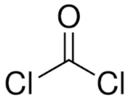
4) Name: ______________ **Student ID:** ______________

Solutions must be written legibly, in the space provided. Adequate detail to the calculation (including units, appropriate sig figs) must be provided to make it possible for other students to understand how you arrived at the final solution. If more space is needed, use the back of the page. Do not add extra pages, as they will not be marked. Assignment pages must be stapled together.

NOTE: For each question a hint, or reference to an Office Hours video, interactive LearningWare (ILW) problem or Chem FAQ module in WileyPLUS is given in brackets.

Question 1. (Video 3.71)
Phosgene (Cl_2CO) is a highly toxic gas that was used for chemical warfare during World War I. Use bond energies in Table 3-2 to estimate the energy change that occurs when carbon monoxide and chlorine combine to make phosgene.

$CO(g) + Cl_2(g) \rightarrow$



$$\Delta E_{\text{REACTION}} = \Sigma BE_{\text{BONDS BROKEN}} - \Sigma BE_{\text{BONDS FORMED}} = 1310\text{ kJ} - 1410\text{ kJ}$$
$$= -100\text{ kJ}$$

BONDS BROKEN $C\equiv O$ $Cl-Cl$
1070 kJ 240 kJ $= 1310\text{ kJ}$

BONDS FORMED $2\times C-Cl$ $C=O$
$2\times 330\text{ kJ}$ 750 kJ $= 1410\text{ kJ}$

Question 2. (Video problem 3.71)

Use the data available in Appendix of the textbook to calculate the standard enthalpy change for

$$3NO_2(g) + H_2O(l) \rightarrow 2HNO_3(g) + NO(g)$$

$$\Delta H^\circ_{REACTION} = \Sigma \nu_p \Delta H^\circ_{f,p} - \Sigma \nu_r \Delta H^\circ_{f,r}$$

$$= [2\,\Delta H^\circ_f(HNO_3) + \Delta H^\circ_f(NO)] - [3\,\Delta H^\circ_f(NO_2) + \Delta H^\circ_f(H_2O)]$$

$$= [2(-133.9\ kJ) + 91.3\ kJ] - [3(33.2\ kJ) + \Delta H^\circ_f(-285.8\ kJ)]$$

$$= \underline{9.7\ kJ}$$

Question 3. (See ChemFAQ about using Hess' Law and writing formation reactions)

The human body "burns" glucose ($C_6H_{12}O_6$) for energy.

(a) Write the balanced equation for the combustion (burning) of glucose.

$$C_6H_{12}O_{6(s)} + 6O_{2(g)} \rightarrow 6\,CO_{2(g)} + 6\,H_2O_{(l)}$$

(b) Determine the molar heat of combustion of glucose, given that burning 1.00 g of glucose produces 15.7 kJ of heat.

$$q = -15.7\,kJ \Longrightarrow$$ FROM 1g $C_6H_{12}O_6$

$$n_{GLUCOSE} = \frac{m}{M}$$

$$= \frac{1.00g}{(6 \times 12.01 + 12 \times 1.008 + 6 \times 16.00)\,g/mol}$$

$$= \frac{1.00g}{180.16\,g/mol} = 5.55\bar{1} \times 10^{-3}\,mol$$

$$\frac{q}{n} = \frac{-15.7\,kJ}{5.551 \times 10^{-3}\,mol} = \underline{-282\bar{8}\,\frac{kJ}{mol}}$$

(c) Write the balanced equation for the formation of glucose.

$$6C_{(s)} + 6H_{2(g)} + 3O_{2(g)} \longrightarrow C_6H_{12}O_{6(s)}$$

(d) Determine the heat of formation of glucose. You may also need to use thermodynamic data from the textbook.

$$\underbrace{\Delta H^\circ_{\text{COMBUSTION}}}_{-2828\text{ kJ}} = \sum \nu_p \Delta H^\circ_{f,p} - \sum \nu_r \Delta H^\circ_{f,r}$$

$$= \left[6\underbrace{\Delta H^\circ_f(CO_{2(g)})}_{-395.5\text{ kJ}} + 6\underbrace{\Delta H^\circ_f(H_2O_{(l)})}_{-285.8\text{ kJ}}\right] - \left[\underbrace{\Delta H^\circ_f(C_6H_{12}O_6)}_{\text{SOLVE FOR THIS}} + 6\underbrace{\Delta H^\circ_f(O_{2(g)})}_{0}\right]$$

$$\Delta H^\circ_f(C_6H_{12}O_6) = 6(-395.5\text{ kJ}) + 6(-285.8\text{ kJ}) - (-2828\text{ kJ})$$

$$= \underline{-1260\text{ kJ}}$$

Question 4. (Office hours video 3.31)

When 10.00 mL of a solution of strong acid is mixed with 100.00 mL of a solution of weak base in a coffee-cup calorimeter, the temperature rises from 21.0 °C to 27.2 °C. Determine *q* for the acid-base reaction, assuming that the liquids have densities of 1.00 g/mL and the same heat capacities as pure water.

$C = 1\text{ CAL g}^{-1}\ {}^\circ C$

$$\frac{m_{H_2O}}{V} = \text{DENSITY}$$

$$m = \text{DENSITY} \times V$$

$$= 1.00\text{ g/mL} \times 110\text{ mL}$$

$$= 110.\text{ g}$$

$$q_{\text{SOLUTION}} = mC\Delta T$$

$$= (110.\text{ g})(1\text{ cal g}^{-1}\,{}^\circ C^{-1})(27.2^\circ C - 21.0^\circ C)$$

$$= 682\text{ cal} \times 4.184\ \frac{J}{\text{cal}}$$

$$= 2850\text{ J}$$

$$q_{\text{REACTION}} = -q_{\text{SOLUTION}} = \underline{-2850\text{ J}}$$

Question 5. (Interactive Learning Ware 3.15)

A 29.2-g graphite block, initially at 75.0 °C, is dropped into a Thermos flask containing 28.1 g of water initially at 4.12 °C. What is the final temperature of the Thermos flask contents? (You may need the data from Table 3.1)

$C_m(C_{(s,\ GRAPHITE)}) = 8.527\ J\ mol^{-1}\ {}^{\circ}C^{-1}$

$C_m(H_2O_{(l)}) = 75.291\ J\ mol^{-1}\ {}^{\circ}C^{-1}$

$T_{1,C(s)} = 75.0\,{}^{\circ}C = 348.1\bar{5}\,K$

$n_{C(s)} = \frac{m}{M} = \frac{29.2\,g}{12.01\,g/mol} = 2.43\bar{1}\ mol$

$T_{1,H_2O} = 4.12\,{}^{\circ}C = 277.27\,K$

$n_{H_2O} = \frac{m}{M} = \frac{28.1\,g}{(1.008 \times 2 + 16.00)\,g/mol} = 1.56\bar{0}\ mol$

$q_{C(s)} = -q_{H_2O}$

$n_{H_2O}\, C_m(H_2O)(T_2 - T_{1,H_2O}) = -n_{C(s)}\, C_m(C(s))(T_2 - T_{1,C(s)})$

SOLVE FOR T_2

$$T_2 = \frac{n_{C(s)} C_m(C(s)) T_{1,C(s)} + n_{H_2O} C_m(H_2O) T_{1,H_2O}}{n_{H_2O} C_m(H_2O) + n_{C(s)} C_m(C(s))}$$

$$= \frac{(2.43\bar{1}\,mol)(8.527\,J\,K^{-1}mol^{-1})(348.1\bar{5}\,K) + (1.56\bar{0}\,mol)(75.291\,J\,K^{-1}mol^{-1})(277.27\,K)}{(1.56\bar{0}\,mol)(75.291\,J\,K^{-1}mol^{-1}) + (2.43\bar{1}\,mol)(8.527\,J\,K^{-1}\,mol^{-1})}$$

$= \underline{288\,K} = \underline{14.8\,{}^{\circ}C}$

Question 6. (Chapter 3, slide 14. You will also need to use what you leaned in Chapter 1 and 2.)

Gases are usually supplied in heavy steel cylinders at high pressure. Compressing a gas into a cylinder requires that work be done by a pump.

a) Calculate the work required to compress 1.00×10^3 L of gas at 298 K, to a final volume of 25.0 L at the same temperature using an external pressure of 250 bar.

NEED TO CONVERT TO S.I UNITS

$250\ bar \times \frac{10^5\ Pa}{bar} = 2.50 \times 10^7\ Pa$

$V_1 = 1.00 \times 10^3\ L \times \frac{10^{-3}\ m^3}{L} = 1.00\ m^3$

$V_2 = 25.0\ L \times \frac{10^{-3}\ m^3}{L} = 2.5 \times 10^{-2}\ m^3$

$W = -p_{ext}\,\Delta V$

$= (2.50 \times 10^7\ Pa)(2.5 \times 10^{-2}\ m^3 - 1.00\ m^3)$

$= \underline{24.3\bar{8}\ kJ}$

b) If the pump used to carry out this compression was driven by burning propane (C_3H_8), how many litres of propane gas at 25°C, 125 kPa must be burned in excess of oxygen to produce the energy required to carry out the work in a). Use the data available in Appendix D.

ENERGY NEEDED = $24.3\bar{8}$ kJ NEED TO CALCULATE HEAT OF COMBUSTION

$$C_3H_{8(g)} + 5O_{2(g)} \rightarrow 3CO_{2(g)} + 4H_2O_{(l)}$$

$$\Delta H^\circ_{\text{COMBUSTION}} = \sum \nu_p \Delta H^\circ_{f,p} - \sum \nu_r \Delta H^\circ_{f,r}$$

$$= 3\underbrace{\Delta H^\circ_f(CO_{2(g)})}_{-393.5} + 4\underbrace{\Delta H^\circ_f(H_2O_{(l)})}_{-285.83} - \underbrace{\Delta H^\circ_f(C_3H_{8(g)})}_{-103.8} - 5\underbrace{\Delta H^\circ_f(O_{2(g)})}_{0}$$

$$= -2220.0\bar{2} \text{ kJ mol}^{-1}$$

$$n_{C_3H_8} = \frac{\Delta H_{\text{NEEDED}}}{\Delta H^\circ_{\text{COMBUSTION}}} = \frac{24.3\bar{8} \text{ kJ}}{2220.0\bar{2} \text{ kJ mol}^{-1}} = 1.09\bar{8} \times 10^{-2} \text{ mol}$$

$$V = \frac{nRT}{p}$$

$$= \frac{(1.09\bar{8} \times 10^{-2} \text{ mol})(8.314 \text{ kPa}\cdot\text{L}\cdot\text{K}^{-1}\text{mol}^{-1})(298 \text{ K})}{125 \text{ kPa}}$$

$$= 217.\bar{8} \text{ mL}$$

c) If 55% of the energy produced by the combustion of propane is lost as heat, how many litres of propane would be required to carry out the work in a)?

55% ENERGY IS LOST AS HEAT

∴ 45% ENERGY IS USED TO DO WORK ≈ % YIELD

$$\Delta H^\circ_{\text{COMBUSTION, ACTUAL}} = \Delta H^\circ_{\text{COMBUSTION, THEORETICAL}} \times \frac{\% \text{ YIELD}}{100\%}$$

$$= -2220.0\bar{2} \text{ kJ/mol} \times 0.45$$

$$= -99\bar{9} \text{ kJ/mol}$$

$$n_{\text{NEEDED}} = \frac{\Delta H_{\text{NEEDED}}}{\Delta H_{\text{COMBUSTION, ACTUAL}}} = \frac{24.38 \text{ kJ}}{999 \text{ kJ mol}^{-1}} = 0.244\bar{0} \text{ mol}$$

$$V = \frac{nRT}{p} = \frac{(0.244\bar{0} \text{ mol})(8.314 \text{ kPa}\cdot\text{L}\cdot\text{K}^{-1}\text{mol}^{-1})(298 \text{ K})}{125 \text{ kPa}}$$

$$= 484 \text{ mL}$$

OR

$$\frac{V_{\text{THEORETICAL}}}{V_{\text{ACTUAL}}} = 0.45$$

$$\therefore V_{\text{ACTUAL}} = \frac{217.8 \text{ mL}}{0.45}$$

$$= 484 \text{ mL}$$