CHEM1612 Answers to Problem Sheet 1

1. **The energy q, required to heat a substance of mass m by a temperature ΔT is given by the equation:**

$$q = c \times m \times \Delta T$$

where c is the specific heat capacity – a property of the substance involved.

If q = 78.2 J, m = 45.6 g and ΔT = 13.3 K, then

$$c = \frac{q}{m\Delta T} = \frac{78.2\,\mathrm{J}}{(45.6\,\mathrm{g})\times(13.3\,\mathrm{K})} = 0.129\,\mathrm{J\,K^{-1}g^{-1}}$$

The atomic mass of lead is 207.2 g mol^{-1}. The molar heat capacity, C, is therefore:

$$C = (0.129\ \mathrm{J\ K^{-1}\ g^{-1}}) \times (207.2\ \mathrm{g\ mol^{-1}}) = 26.7\ \mathrm{J\ K^{-1}\ mol^{-1}}.$$

2. **The neutralization reaction is a 1:1 reaction with chemical equation:**

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$$

After the reactants mix the solution has a volume of 200 mL. Assuming the solution the same density as pure water, this corresponds to a mass of:

$$\begin{aligned}\text{mass (g)} &= \text{density (g mL}^{-1}) \times \text{volume (mL)}\\ &= (0.997\ \text{g mL}^{-1}) \times (200\ \text{mL}) = 199\ \text{g}\end{aligned}$$

The temperature change, ΔT = (31.1 °C – 24.6 °C) = 6.7 K. The heat capacity of water is 4.184 J K^{-1} g^{-1}. The heat change is therefore:

$$\begin{aligned}q = c \times m \times \Delta T &= (4.184\ \mathrm{J\ K^{-1}\ g^{-1}}) \times (199\ \mathrm{g}) \times (6.7\ \mathrm{K})\\ &= 5600\ \mathrm{J}\ \text{or}\ 5.6\ \mathrm{kJ}\quad \text{(heat released)}\end{aligned}$$

The number of moles of H^+ and OH^- present are both the same:

$$\begin{aligned}\text{number of moles} &= \text{concentration (M or mol L}^{-1}) \times \text{volume (L)}\\ &= (1.0\ \text{mol L}^{-1}) \times (0.100\ \text{mL}) = 0.1\ \text{mol}\end{aligned}$$

The heat change for a mole would therefore be 5.6 kJ / 0.1 mol = 56 kJ mol^{-1}. The reaction gives out heat (as the temperature rises) so it is an exothermic reaction with a negative enthalpy change: ΔH = –56 kJ mol^{-1}

3. (a) $2(NH_2)_2CO(s) + 3O_2(g) \rightarrow 4H_2O(l) + 2N_2(g) + 2CO_2(g)$

(b) **The molar mass of urea, $(NH_2)_2CO$, is:**

$$\text{molar mass} = 2\times(14.01\ (\text{N}) + 2\times1.008\ (\text{H})) + 12.01\ (\text{C}) + 16.00\ (\text{N}) = 60.062\ \text{g mol}^{-1}$$

The number of moles present in 6.006 g is therefore:

$$\textbf{number of moles} = \frac{\textbf{mass}}{\textbf{molar mass}} = \frac{\textbf{6.006 g}}{\textbf{60.062 g mol}^{-1}} = \textbf{0.1000 mol}$$

As this amount releases 63.4 kJ, the amount release by a mole is:

$$\Delta_{comb}H° = -\frac{63.4\ \text{kJ}}{0.1000\ \text{mol}} = -634\ \text{kJ mol}^{-1}$$

The reaction is *exothermic* as energy is *liberated* or *released*: $\Delta H°$ is negative.

(c) **The chemical equation given in (a) corresponds to combusting *two* moles of $(NH_2)_2CO(s)$. The enthalpy of the reaction is therefore:**

$$\Delta_{rxn}H° = 2 \times \Delta_{comb}H° = 2 \times -634 = -1268\ \text{kJ mol}^{-1}$$

Using $\Delta_{rxn}H^o = \sum m\Delta_f H^o(\text{products}) - \sum n\Delta_f H^o(\text{reactants})$,

$$\Delta_{rxn}H^o = [4\Delta_f H^o(H_2O(l)) + 2\Delta_f H^o(N_2(g)) + 2\Delta_f H^o(CO_2(g))] - [2\Delta_f H^o((NH_2)_2CO(s)) + 3\Delta_f H^o(O_2(g))]$$

As $\Delta_f H^o = 0$ **for an element in its standard state, this becomes:**

$$\Delta_{rxn}H^o = [(4\times -285) + (2\times 0) + (2\times -393)] - [2\Delta_f H^o((NH_2)_2CO(s)) + (3\times 0)] = -1268\ \text{kJ mol}^{-1}$$

Hence, $\Delta_f H^o((NH_2)_2CO(s)) = -329\ \text{kJ mol}^{-1}$.

4. **The temperature change, ΔT = 27.828 – 25.000 = 2.828 °C.**

As the temperature increases, heat is lost from the system and gained by the surroundings. The reaction is exothermic.

The heat change is given by:

$$q = c \times \Delta T = (96.5\ \text{kJ °C}^{-1}) \times (2.828\ \text{°C}) = 273\ \text{kJ}$$

This is the heat change for 0.0100 mol of propane, the internal energy change for 1 mol is therefore:

$$\Delta U = -\frac{273\ \text{kJ}}{0.0100\ \text{mol}} = -2.73\times 10^5\ \text{kJ mol}^{-1}$$

The negative sign indicates that the system is losing energy to the surroundings. As a bomb calorimeter has a constant volume, the heat change is related to a change in internal energy, ΔU.