Enthalpy Wrap Up Problems

1. Carbon is found in several forms. Graphite and diamond are common forms known for millennia; other forms, such as buckyballs, were discovered only in the last few decades. Combustion of graphite in the presence of oxygen forms carbon dioxide as a product releasing 394 kJ of energy per mole of C atoms.

$$\mathrm{C}(s) + \mathrm{O}_2(g) \longrightarrow \mathrm{CO}_2(g)$$

Combustion of buckyballs, C_{60}, on the other hand, releases approximately 26,100 kJ of energy per mole ofC_{60}, or 435 kJ per mole of C atoms.

$$\mathrm{C}_{60}(s) + 60\,\mathrm{O}_2(g) \longrightarrow 60\,\mathrm{CO}_2(g)$$

Which of these forms of carbon has the stronger average carbon-carbon bond? Clearly explain your reasoning.

Answer. Converting a mole of buckyballs to CO_2 releases more energy per mole of carbon than converting a mole of graphite to CO_2. We know that a reaction is exothermic (energy released) when we move from reactants with weaker bonds to products with stronger bonds. Because both reactions have the same final state (CO_2) and because buckyballs release more energy per mole of C, this form of carbon must have the weaker bonds (see Figure 1 below). Graphite, therefore, has the stronger bonds.

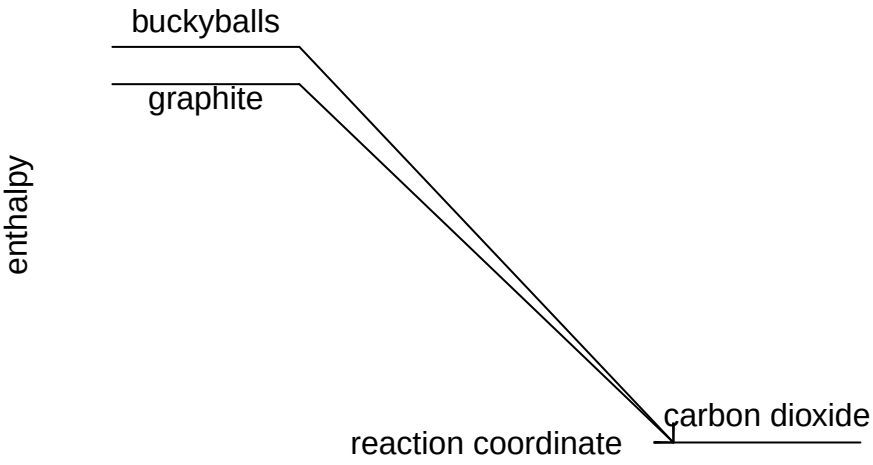

Figure 1: Enthalpy change for combustion of graphite and buckyballs

An alternative way to reach the same conclusion is to imagine reactions that convert both graphite and buckyballs to gas-phase carbon atoms and then allow the atoms to react with O_2 to form CO_2; the energy diagram now looks like that in Figure 2 below.

The energy needed to convert buckyballs to $\mathrm{C}(g)$ is less than the energy needed to convert graphite to $\mathrm{C}(g)$; thus, the carbon-carbon bonds in buckyballs are weaker than those in graphite.

In an experiment to determine the enthalpy of dissolution for solid NaOH

$$\mathrm{NaOH}(s) \rightarrow \mathrm{Na}^+(aq) + \mathrm{OH}^-(aq)$$

you dissolve 2.0 g of solid NaOH in 100.0 mL of water and observe a temperature increase. In a second experiment you add 4.0 g of NaOH to 200.0 mL of water. Do you expect the change in temperature for the second experiment to be:

(a) the same as that of the first experiment

(b) approximately twice that of the first experiment

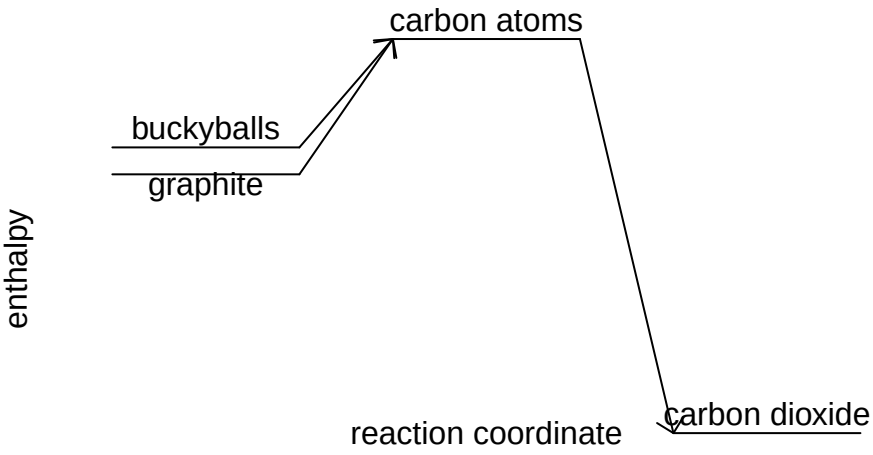

Figure 2: Enthalpy change for combustion of graphite and buckyballs via carbon atoms

(c) approximately four times that of the first experiment

(d) approximately one-half of that for the first experiment

(e) approximately one-fourth of that for the first experiment?

Explain your reasoning.

Answer. If the amount of heat released when 2.0 g of NaOH dissolves is x, then $q_{rxn1} = x$. The amount of heat released when dissolving 4.0 g of NaOH is twice as great, or $2x$, and $q_{rxn2} = 2x$. In each case the amount of heat absorbed by the solution, q_{soln}, is equal in magnitude but opposite in sign from q_{rxn}; thus, assuming a density of 1.00 g/mL, we find that

$$q_{soln1} = (100.0 \text{ g}) \times (4.184 \text{J/g} \bullet {}^{o}\text{C}) \times \Delta T_1 = -x$$

$$q_{soln2} = (200.0 \text{ g}) \times (4.184 \text{J/g} \bullet {}^{o}\text{C}) \times \Delta T_2 = -2x$$

Solving each equation for ΔT shows that ΔT_1 and ΔT_2 are the same for both reactions.