Thermochemistry I: Energy Transfer and Calorimetry

1. What amount of work (in J) is performed on the surroundings when a 1.0 L balloon at 745 mm Hg at 25°C is heated to 45°C? (1 L·atm = 101.325 J)

$$w = -P\Delta V$$
$$P = \frac{745\text{ mm Hg}}{760\,\frac{\text{mm Hg}}{\text{atm}}} = 0.9803\text{ atm}$$
$$T_i = 25°\text{C} + 273\text{ K} = 298\text{ K} \qquad T_f = 45°\text{C} + 273\text{ K} = 318\text{ K}$$
$$V_f = V_i\left(\frac{T_f}{T_i}\right) = 1.0\text{ L}\left(\frac{318\text{ K}}{298\text{ K}}\right) = 1.07\text{ L}$$
$$\Delta V = 1.07\text{ L} - 1.0\text{ L} = 0.07\text{ L}$$
$$w = -(0.9803\text{ atm})(0.07\text{ L}) \times 101.325\,\frac{\text{J}}{\text{L·atm}} = -7.0\text{ J}$$

2. What quantity of heat (in J) is necessary to raise 3.00 L of water (*d*=1.00 g/mL) from 22.0°C to 63.0°C?

$$q = mc\Delta T$$
$$m = 3.00\text{ L} \times \frac{1000\text{ g}}{1\text{ L}} = 3000\text{ g } (\pm 10\text{ g})$$
$$c = 4.184\,\frac{\text{J}}{\text{g·°C}}$$
$$\Delta T = 63.0°\text{C} - 22.0°\text{C} = 41.0°\text{C}$$
$$q = (3000\text{ g})(4.184\,\tfrac{\text{J}}{\text{g·°C}})(41.0°\text{C}) = 515{,}000\text{ J}$$

3. A 200.0 mL quantity of 0.40 M HCl was added to 200.0 mL of 0.40 M NaOH in a solution (constant pressure) calorimeter. The temperature of each solution was 25.10°C before mixing. After mixing the solution rose to a temperature of 26.60°C before beginning to cool. The heat capacity of the calorimeter was determined by separate experiment to be 55 J/°C. What is ΔH_{rxn} per mol of H_2O formed? Assume the solutions have a density of 1.00 g/mL and their specific heats are similar to water; c = 4.18 J/g·°C.

$$V_{\text{HCl}} = 200.0\text{ mL} \qquad V_{\text{NaOH}} = 200.0\text{ mL}$$
$$m_{\text{HCl}} = 200.0\text{ g} \qquad m_{\text{NaOH}} = 200.0\text{ g}$$
$$n_{\text{HCl}} = 0.2000\text{ L}(0.40\text{M}) = 0.080\text{ mol HCl} \qquad n_{\text{NaOH}} = 0.080\text{ mol NaOH}$$

$$q_{\text{rxn}} + q_{\text{soln}} + q_{\text{cal}} = 0$$
$$q_{\text{rxn}} = n\Delta H_{\text{rxn}} \qquad q_{\text{soln}} = mC\Delta T \qquad q_{\text{cal}} = C\Delta T$$
$$m_{\text{soln}} = 400.0\text{ g} \qquad c_{\text{soln}} = 4.184\,\tfrac{\text{J}}{\text{g·°C}} \qquad \Delta T = 26.60°\text{C} - 25.10°\text{C} = 1.50°\text{C}$$

$$(0.080\text{ mol})\Delta H + 400.0\text{ g}(4.184\,\tfrac{\text{J}}{\text{g·°C}})(1.50°\text{C}) + 55\,\tfrac{\text{J}}{°\text{C}}(1.50°\text{C}) = 0$$
$$(0.080\text{ mol})\Delta H = -2590.5\text{ J}$$
$$\Delta H = -32{,}400\,\tfrac{\text{J}}{\text{mol}}$$

4. A 1.00 g sample of table sugar (sucrose, $C_{12}H_{22}O_{11}$) was burned in a bomb calorimeter (constant volume calorimeter) containing 1.50 kg of water. The temperature of the water in the calorimeter rose from 25.00°C to 27.32°C. What is the $\Delta H_{\text{combustion}}$ of sucrose in kJ/g and kJ/mol? The heat capacity of the calorimeter was determined by separate experiment to be 837 J/°C.

$$n_{\text{sucrose}} = {}^{1.00\text{ g}}\!\Big/_{342.2\,\frac{\text{g}}{\text{mol}}} = 2.922\times10^{-3}\text{ mol}$$

$$m_{H_2O} = 1500\text{ g} \qquad \Delta T = 27.32°\text{C} - 25.00°\text{C} = 2.32°\text{C}$$

$$q_{\text{rxn}} + q_{\text{soln}} + q_{\text{cal}} = 0$$

$$q_{\text{rxn}} = n\Delta H_{\text{rxn}} \qquad q_{\text{soln}} = mC\Delta T \qquad q_{\text{cal}} = C\Delta T$$

$$(2.922\times10^{-3}\text{ mol})\Delta H_{\text{combustion}} + 1500\text{ g}(4.184\,\tfrac{\text{J}}{\text{mol}\cdot\text{K}})(2.32°\text{C}) + 837\,\tfrac{\text{J}}{°\text{C}}(2.32°\text{C}) = 0$$

$$(2.922\times10^{-3}\text{ mol})\Delta H_{\text{combustion}} = -16502\text{ J}$$

$$\Delta H_{\text{combustion}} = -5.65\times10^{6}\,\tfrac{\text{J}}{\text{mol}} = -5650\,\tfrac{\text{kJ}}{\text{mol}}$$

$$\Delta H_{\text{combustion}} = \frac{-16502\text{ J}}{1.00\text{ g}} = -16{,}502\,\tfrac{\text{J}}{\text{g}} = -16.5\,\tfrac{\text{kJ}}{\text{g}}$$

5. Camphor ($C_{10}H_{16}O$) has a $\Delta H_{\text{combustion}}$ of-5903.6 kJ/mol. A 0.7610 g sample of camphor was burned in a bomb calorimeter containing 2.00 x 10^3 g of water. The temperature of the water increased from 22.78°C to 25.06°C. What is the heat capacity of the calorimeter?

$$M_{\text{camphor}} = 152.23\,\tfrac{\text{g}}{\text{mol}}$$

$$n_{\text{camphor}} = {}^{0.7610\text{ g}}\!\Big/_{152.23\,\frac{\text{g}}{\text{mol}}} = 0.004999\text{ mol}$$

$$\Delta T_{\text{cal},H_2O} = 25.06°\text{C} - 22.78°\text{C} = 2.28°\text{C}$$

$$q_{\text{rxn}} + q_{\text{soln}} + q_{\text{cal}} = 0$$

$$q_{\text{rxn}} = n\Delta H_{\text{rxn}} \qquad q_{\text{soln}} = mC\Delta T \qquad q_{\text{cal}} = C\Delta T$$

$$(0.004999\text{ mol})(-5903.6\times10^{3}\,\tfrac{\text{J}}{\text{mol}}) + 2000\text{ g}(4.184\,\tfrac{\text{J}}{\text{mol}\cdot\text{K}})(2.28°\text{C}) + C_{\text{cal}}(2.28°\text{C}) = 0$$

$$-29512.6\text{ J} + 19079\text{ J} + C_{\text{cal}}(2.28°\text{C}) = 0$$

$$C_{\text{cal}}(2.28°\text{C}) = 10433.5\text{ J}$$

$$C_{\text{cal}} = 4576\,\tfrac{\text{J}}{°\text{C}}$$