Learning Goal

I can solve problems involving the transfer of thermal energy (heat).

Summary

- Heat is the quantity of thermal energy transferred to/from a substance.
- Like all quantities of energy, heat is measured in joules (J).
- A positive heat value means that the substance gained thermal energy (energy was transferred *to* the substance).
- A negative heat value means that the substance lost thermal energy (energy was transferred *from* the substance).
- Heat can be calculated using the formula $\mathbf{q=mc\Delta T}$.
  - **q** is heat (quantity of heat transferred)
  - **m** is mass of the substance
  - **c** is the specific heat capacity of the substance
  - $\mathbf{\Delta T}$ is the change in temperature of the substance ($\Delta T = T_2 - T_1$)
- The formula can be rearranged to calculate any of the variables depending on what data you have.

Example Quantitative Problem

A pot contains 2.5 L of water at 20.3°C. Calculate the final temperature of the water when 187 kJ of thermal energy is transferred to the water by a heating coil.

SOLUTION

Given: $V_{H20} = 2.5\text{L}$ ⇦ Because the density of water is 1g/mL, the mass of the water is 2500 g.

$T_1 = 20.3°\text{C}$

$q = +187\ \text{kJ}$ ⇦ Positive value because the energy is *transferred to the water*.

$c_w = 4.18\ \text{J g}^{-1}°\text{C}^{-1}$ ⇦ The specific heat capacity for water is known.

Required: $T_2 = ?$

Analysis:

$$q = mc\Delta T$$

$$q = mc(T_2 - T_1)$$

$$\frac{q}{mc} = T_2 - T_1$$ ⇦ Rearrange equations before entering values.

$$\frac{q}{mc} + T_1 = T_2$$

$$T_2 = \frac{q}{mc} + T_1$$

Solution:

$$T_2 = \frac{+\underline{187}\ 000\ \cancel{\text{J}}}{(\underline{2500}\ \cancel{\text{g}})(\underline{4.18}\ \cancel{\text{J}}\ \cancel{\text{g}^{-1}}°\text{C}^{-1})} + \underline{20.3}°\text{C}$$

⇦ Show unit analysis.

⇦ Significant figures are underlined.

$$= \underline{17}.8947...°\text{C} + \underline{20.3}°\text{C}$$

$$= \underline{38}.1947...°\text{C}$$

Statement:

Therefore, the final temperature of the water is 38°C

Practice Problem 1

When 150 g of acetone cools from 63°C to 25°C, the acetone releases 12.3 kJ of thermal energy. Calculate the specific heat capacity of acetone.

(ANSWER $2.2\ \text{J g}^{-1}°\text{C}^{-1}$)

2. ENTHALPY CHANGE

Learning Goal
I can solve quantitative problems involving enthalpy changes.

Summary
- Enthalpy change is the quantity of thermal energy released or absorbed by a chemical reaction.
- Like all quantities of energy, enthalpy change is measured in joules (J).
- A positive enthalpy change means that the reaction absorbs energy (endothermic reaction).
- A negative enthalpy change means that the reaction releases energy (exothermic reaction).
- Molar enthalpy change is the change in enthalpy per mole of substance.

$$\Delta H_x = \frac{\Delta H}{n}$$

ΔH_x is the molar enthalpy change
ΔH is the total enthalpy change
n is the amount of the substance causing the total enthalpy change

Example Quantitative Problem
How much thermal energy is released when 60.0 g of potassium metal reacts according to the following equation?

$$2\ K(s)\ +\ 2\ H_2O(l)\ \rightarrow\ 2\ KOH(aq)\ +\ H_2(g)\ +\ 160\ kJ$$

SOLUTION

1. Convert the energy term in the chemical equation to a molar enthalpy change.

n_K = 2 mol ⇦ From the chemical equation (**2** K(s) + . . .)

$\Delta H = -160$ kJ ⇦ From the chemical equation; negative because the energy is released

$$\Delta H_x = \frac{\Delta H}{n} = \frac{-\underline{160}\ kJ}{2\ mol^*} = -\underline{80}\ kJ/mol$$ ⇦ with respect to potassium

*The 2 mol from the chemical equation is not a measured value. The 2 is an exact number, and does not affect significant figures in the calculation.

2. Calculate the amount (in moles) of potassium reacting.

$$n_K = \frac{m_K}{M_K} = \frac{\underline{60.0}\ \cancel{g}}{\underline{39.10}\ \cancel{g}\ mol^{-1}} = \underline{1.53}45...\ mol$$ ⇦ Show unit analysis.

3. Calculate the enthalpy change cause by this amount of potassium.

$$\Delta H = n\,\Delta H_x = (\underline{1.53}45...\ \cancel{mol})(-\underline{80}\ kJ/\cancel{mol}) = -\underline{12}2.762...\ kJ$$ ⇦ Show unit analysis.

Therefore, the thermal energy released is 1.2×10^2 kJ. ⇦ The term "released" replaces the negative sign.

Practice Problem 2
What mass of butane must burn to release 6500 kJ of thermal energy?

$$2\ C_4H_{10}(g)\ +\ 13\ O_2(g)\ \rightarrow\ 8\ CO_2(g)\ +\ 10\ H_2O(g)\ +\ 5756\ kJ$$

(ANSWER 0.13 kg)

3. CALORIMETRY

Learning Goal

I can analyse calorimetry data to find the molar enthalpy change for a chemical reaction or physical change.

Summary

- Calorimetry is a technique for measuring the enthalpy change for a reaction.
- The calorimeter is an isolated system (not perfectly but close enough to assume in the calculations).
- Therefore, the thermal energy lost by the chemical reaction is equal to the thermal energy gained by the contents of the calorimeter (or vice versa).

Example Quantitative Problem

Refer to the solutions to the practice questions in Lesson 4: Calorimetry.

Practice Problem 3

A chemistry student is experimentally determining the molar enthalpy change with respect to potassium hydroxide for the following neutralization reaction.

$$HNO_3(aq) + KOH(s) \rightarrow KNO_3(aq) + H_2O(l)$$

She adds solid potassium hydroxide to nitric acid solution in a polystyrene calorimeter, and collects the following data.

mass of potassium hydroxide put in calorimeter = 5.16 g
volume of nitric acid put in calorimeter = 198.3 mL
initial temperature of the solution = 21.0 °C
final temperature of the solution = 28.1 °C

Complete the analysis. Clearly present all calculations including unit analysis, and state any assumptions that you make. Write a conclusion.

(ANSWER –64 kJ/mol KOH)