CH 222 Chapter Nine Concept Guide

1. Specific Heat

Question

How much heat is needed to raise the temperature of 28 g of aluminum from 27 °C to 163 °C? No phase changes occur. The specific heat of aluminum is 0.902 J/K*g.

Approach

The amount of heat needed is found from the known mass of Al, the change in temperature, and the specific heat of Al. The following equation relates heat to these values: q = (mass)(specific heat)(temperature change).

Solution

ΔT = 163 °C - 27 °C = 136 °C, or 136 K.
q = (mass)(specific heat)(temperature change)
q = (28 g)(0.902 J/K*g)(136 K)
q = 3400 J

Note that the temperature increased and q is positive. Heat was added to the aluminum, so the direction of heat flow was into the system.

2. Specific Heat

Question

What quantity of heat is needed to raise the temperature of 130 g of water by 5.0 °C? The specific heat of water is 4.184 J/K*g.

Approach

The following equation relates heat to mass and temperature change:
q = (mass)(specific heat)(temperature change).

Solution

ΔT = 5.0 °C, or 5.0 K
q = (mass)(specific heat)(temperature change)
q = (130 g)(4.184 J/K*g)(5.0 K)
q = 2700 J

Note that the temperature increased and q is positive.

3. Molar Heat Capacity

Problem

125 J of heat was absorbed by 1.00 mol of iron, resulting in a temperature change of 4.02 °C. Calculate the molar heat capacity of iron.

Approach

Molar heat capacity can be calculated using the following equation:
q = (number of moles)(molar heat capacity)(temperature change).

Solution

q = (number of moles)(molar heat capacity)(temperature change).
125 J = (1.00 mol iron)(molar heat capacity of iron)(4.02 °C)
molar heat capacity of iron = 125 J / (1.00 mol iron)(4.02 °C)
molar heat capacity of iron = 31.1 J/mol*K

4. Molar Heat Capacity

Heat capacity values are tabulated in two ways: as molar heat capacity, and as specific heat capacity, which has already been discussed in this lesson. Molar heat capacity differs from specific heat capacity in that the former is the amount of heat required to raise the temperature of one mole of a substance by one Kelvin (J/K*g). You may recall that the specific heat is the amount of heat required to raise the temperature of one gram of a substance by one Kelvin (J/K*g).

The molar heat capacity may be calculated using the following equation:

q = (number of moles)(molar heat capacity)(temperature change)

where q is heat in joules. The molar heat capacity has units of J/K*mol. For example, the specific heat of Cu is 0.385 J/K*g. Its molar heat capacity is, therefore, 24.5 J/K*mol.

5. Hess's Law: Heats of Reaction

Problem

Using the following thermochemical data, calculate ΔH° for:
$CaC_2(s) + 2\ H_2O(l) \rightarrow Ca(OH)_2(aq) + C_2H_2(g)$

Thermochemical Equation	ΔH° (kJ)
1. $Ca(s) + 2\ C(graphite) \rightarrow CaC_2(s)$	-59.8
2. $Ca(s) + {}^1/_2\ O_2(g) \rightarrow CaO(s)$	-635.09
3. $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(aq)$	-653.1
4. $C_2H_2(g) + 5/2\ O_2(g) \rightarrow 2\ CO_2(g) + H_2O(l)$	-1300.
5. $C(graphite) + O_2(g) \rightarrow CO_2(g)$	-393.509

Approach

We need to add a series of reactions for which ΔH° is known, to yield the overall reaction of interest. We can manipulate the known reactions as we do this. If necessary, reverse some of the known thermochemical equations so that the major reactants and products of the desired equation are on the appropriate sides. Then, if necessary multiply the known equations by appropriate coefficients so the major reactants and products have the same coefficients as in the desired equation. Add the known equations and the values of ΔH° to obtain ΔH° for:
$CaC_2(s) + 2\ H_2O(l) \rightarrow Ca(OH)_2(aq) + C_2H_2(g)$

Solution
The first, third, and fourth equations include the major reactants and products, yet equations 1 and 4 must be reversed so that the reactants and products are on the appropriate sides according to the desired equation. Only multipliers are needed, as the coefficients are the same in the known equations as in the desired equation.

$CaC_2(s)$ → ~~$Ca(s)$~~ + ~~$2\ C(graphite)$~~ ΔH° = 59.8 kJ

~~$CaO(s)$~~ + $H_2O(l)$ → $Ca(OH)_2(aq)$ ΔH° = -653.1

~~$2\ CO_2(g)$~~ + $H_2O(l)$ → $C_2H_2(g)$ + ~~$5/2\ O_2(g)$~~ ΔH° = 1300.

~~$Ca(s)$~~ + ~~$\frac{1}{2}\ O_2(g)$~~ → ~~$CaO(s)$~~ ΔH° = -635.09

~~$2\ C(graphite)$~~ + ~~$2\ O_2(g)$~~ → ~~$2\ CO_2(g)$~~ ΔH° = -787.018

$CaC_2(s) + 2\ H_2O(l) \rightarrow Ca(OH)_2(aq) + C_2H_2(g)$ ΔH° = -715 kJ

This reaction is exothermic and has a ΔH° = -715 kJ.

6. Hess's Law

Problem
The following data are the thermochemical equations for iron oxides. Find ΔH° for:
$4\ FeO(s) \rightarrow Fe(s) + Fe_3O_4(s)$

Thermochemical Equation	ΔH° (kJ)
1. $Fe(s) + {}^1/_2\ O_2(g) \rightarrow FeO(s)$	-272.0
2. $3\ Fe(s) + 2\ O_2(g) \rightarrow Fe_3O_4(s)$	-1118.4

Approach
We need to add a series of reactions for which ΔH° is known, to yield the overall reaction of interest. We can manipulate the known reactions as we do this. If necessary, reverse some of the known thermochemical equations so that the major reactants and products of the desired equation are on the appropriate sides. Then, if necessary multiply the known equations by appropriate coefficients so the major reactants and products have the same coefficients as in the desired equation. Add the known equations and the values of ΔH° to obtain ΔH° for:
$4\ FeO(s) \rightarrow Fe(s) + Fe_3O_4(s)$

Solution
Equation 1 must be reversed and multiplied by 4 so that the reactants and products are on the appropriate side and the coefficients are the same as in the desired equation.

$4\ Fe(s) + 2\ O_2(g) \rightarrow 4\ FeO(s)$ ΔH° = 1088. kJ

$3\ Fe(s) + 2\ O_2(g) \rightarrow Fe_3O_4(s)$ ΔH° = -1118.4 kJ

$4\ FeO(s) \rightarrow Fe(s) + Fe_3O_4(s)$ ΔH° = -30.4 kJ

This reaction is exothermic and has ΔH° = -30.4 kJ.

7. Heats of Reaction

Problem

Given that the standard heat of formation of PbO(s) at 298 K is -218.99 kJ/mol, write the thermochemical equation for the formation of PbO(s).

Approach

The equation must use the elements in their standard states at 298 K as reactants, and one mole of PbO(s) in its standard state as the product. In their standard states, lead is a solid and oxygen is gas.

Solution

The unbalanced reaction is:

$Pb(s) + O_2(g) \rightarrow PbO(s)$

Now, balance the equation by putting a coefficient of $^1/_2$ before O_2. Remember: we must form a single mole of PbO_2.

$Pb(s) + {}^1/_2\, O_2(g) \rightarrow PbO(s)$

The heat of reaction of PbO(s) is given as -218.99 kJ/mol, so the complete reaction is:

$Pb(s) + {}^1/_2\, O_2(g) \rightarrow PbO(s) \qquad \Delta H° = -218.99\ kJ$

8. Calorimetry

Problem

A 40.00 mg sample of naphthalene, $C_{10}H_8$, was combusted in a calorimeter containing 750. g H_2O. The temperature of the calorimeter increased from 25.000 °C to 25.404 °C. The calorimeter has a heat capacity (calorimeter constant) of 465 J/°C. Calculate $\Delta H°_{combustion}$ for naphthalene in kJ/mol.

Approach

First, calculate the energy to heat the water, q_{water}. Then, calculate the energy to heat the calorimeter vessel, $q_{calorimter}$. The total energy transferred is the sum of these two numbers, q_{system}. Next, convert the mass of the naphthalene sample into moles. Finally, solve for the heat transfer using q_{system} and the moles of naphthalene.**Solution**

Step 1. Solve for q_{water}.

$q(J)_{water} = 750.\ g * 4.184\ J/g\ K * 0.404\ K = 1.27 \times 10^3\ J$

Step 2. Solve for $q_{calorimeter}$.

$q(J)_{calorimeter} = 465\ J/K * 0.404\ K = 1.88 \times 10^2\ J$

Step 3. Solve for q_{system}, which is the negative of the total energy transferred.

Total energy transferred = $-q(J)_{system}$
$= -(1.27 \times 10^3\ J + 1.88 \times 10^2\ J) = -1.46\ kJ$

Step 4. Convert mass of naphthalene to moles naphthalene using the molar mass.

0.0400 g naphthalene * 1 mol naphtlanene/128.17 g naphthalene
$= 3.12 \times 10^{-4}$ mol naphthalene

Step 5. Finally, solve for heat transfer by dividing q_{system} in kilojoules by the moles of naphthalene.

$\Delta H° = -1.46\ kJ/3.12 \times 10^{-4}$ mol naphthalene $= -4.66 \times 10^3\ kJ/mol$

9. Calculating ΔH through Bond Enthalpies

Problem

Calculate ΔH for

$H_2(g) + F_2(g) \rightarrow 2\ HF(g)$.

using the bond energy data below.

H-H = 436 kJ/mol
F-F = 159 kJ/mol
H-F = 569 kJ/mol

Solution

In this reaction, we need to break the bonds between H-H and F-F and will form 2 H-F bonds. Because all the reactants and products are in the gas phase, we can relate ΔH for the reaction to the strengths of bonds broken and formed.

ΔH = (energy of bonds broken) - (energy of bonds formed)
ΔH = [(1mol)(436 kJ/mol) + (1 mol)(159 kJ/mol)] - (2 mol)(569 kJ/mol)
ΔH = -543 kJ

10. Calculating ΔH through Bond Enthalpies

Problem

Calculate ΔH for

$H_2(g) + Br_2(g) \rightarrow 2\ HBr(g)$.

using the bond energy data given below.

H-H = 436 kJ/mol
Br-Br = 192 kJ/mol
H-Br = 368 kJ/mol

Solution

In this reaction, we need to break the bonds between H-H and Br-Br and will form 2 H-Br bonds.

ΔH = (energy of bonds broken) - (energy of bonds formed)
ΔH = [(1 mol)(436 kJ/mol) + (1 mol)(192 kJ/mol)] - (2 mol)(368 kJ/mol)]
ΔH = -108 kJ

11. Calculating ΔH through Bond Enthalpies

Problem

Calculate ΔH for

$C_4H_{10}(g) + 13/2\ O_2(g) \rightarrow 4\ CO_2(g) + 5\ H_2O(g)$

using the bond energy data given below.

C-C = 331 kJ/mol
C-H = 414 kJ/mol
O=O = 498 kJ/mol
C=O = 803 kJ/mol
O-H = 464 kJ/mol

Solution

In this reaction, find that 3 C-C, 10 C-H, and $^{13}/_{2}$ O=O bonds are being broken, and 8 C=O and 10 O-H bonds are being formed. Thus

ΔH = (energy of bonds broken) - (energy of bonds formed)

ΔH = [(3 mol)(331 kJ/mol) + (10 mol)(414 kJ/mol) + (13/2 mol)(498 kJ/mol)] - [(8 mol)(803 kJ/mol) + (10 mol)(464 kJ/mol)]

ΔH = -2694 kJ