Unit 3 Review: Thermochemistry

A. Definition Questions: you should be able to use or apply the following terms. Be able to **write** complete definitions for the terms in **bold**.

energy	**temperature**	standard state
potential energy	**heat**	allotropes
kinetic energy	**specific heat capacity**	**standard heat of formation**
enthalpy	endothermic	**bond energy**
thermal kinetic energy	exothermic	

1. Identify the **INCORRECT** statement below:

a) potential energy is the energy an object has because of its position relative to and attraction toward another object
b) energy is the ability to do work
c) in an exothermic reaction, the enthalpy of the products is higher than the enthalpy of the reactants
d) in an ordinary chemical reaction, energy is neither created nor destroyed

2. A particular chemical reaction has $\Delta H^o = +250$ kJ/mol. Which of the following statements is/are true concerning this reaction?

I) Heat moves from the system to the surroundings
II) The reaction is endothermic
III) The enthalpy of the products is lower than the enthalpy of the reactants

a) I and II only
b) II only
c) II and III only
d) I, II and III are true

3. Which of the following molecules has the highest enthalpy?

a) propane
b) cyclopropane
c) pentane
d) cyclooctane

4. Which statement is **INCORRECT** about endothermic reactions?

a) the system absorbs energy from its surroundings
b) the enthalpy of products is lower than the enthalpy of the reactants
c) the thermal kinetic energy of the surroundings will decrease
d) the enthalpy change will have a positive value

5. All of the following statements are true **EXCEPT**:

a) ΔH for a reaction is equal in magnitude but opposite in sign to ΔH for the reverse reaction
b) enthalpy is a state function
c) the overall change in enthalpy for a reaction depends on the number of steps in a reaction
d) chemical potential energy contributes to the total enthalpy of a substance

6. What is the definition of the temperature of a substance?

a) the total heat content of a the particles in a substance
b) the speed of the fastest particles in the substance
c) the speed of the slowest particles in the substance
d) the average kinetic energy of the particles in a system

7. Which of the following is the standard state of carbon at SATP?

a) C as CO_2 (g)
c) C as graphite (s)
b) C as CH_4 (g)
d) C as diamond (s)

8. What is the definition of the specific heat capacity of a substance?

a) the amount of energy required to raise the temperature of 1 g of a substance by 1ºC
b) the amount of energy required to raise the temperature of 1 mol of substance by 1ºC
c) the amount of energy required to raise the temperature of 1 kg of a substance by 1ºC
d) the amount of energy required to raise the temperature of 1 g of a substance by 100ºC

9. Which substance has the highest specific heat capacity?

a) water
c) aluminum
b) iron
d) sand

10. When a sample of potassium nitrate is dissolved in water, the temperature of the water changes from 23.5ºC to 20.3ºC. Which statement describes this process?

a) this process is exothermic, so the surroundings get cooler
b) this process is exothermic, so the surroundings get warmer
c) this process is endothermic, so the surroundings get cooler
d) this process is endothermic, so the surroundings get warmer

11. Which of the following statements is/are true about an exothermic reaction?

I) the energy absorbed in bond breaking is more than the energy released in bond formation
II) the system absorbs energy
III) the potential energy of the reactants is less than the potential energy of the products
IV) the thermal kinetic energy of the surroundings will increase

a) I and III only
c) II and III only
b) II and IV only
d) IV only

12. Which statement does NOT describe an endothermic reaction?

a) the surroundings cool down
b) ΔH^o_{rxn} is positive
c) heat is released by the system
d) the potential energy of the products is greater than the potential energy of the reactants

B. Stoichiometry with Thermochemical Equations:

13. Given: $H_2(g) + Br_2(l) \rightarrow 2\ HBr(g) \quad \Delta H^o = -72.8$ kJ

Calculate the amount of energy absorbed or released when 15.0 g of HBr (*g*) is formed.

a) 6.75 kJ released
c) 13.5 kJ released
b) 4.85 kJ absorbed
d) 607 kJ absorbed

14. How much heat is absorbed when 3.00 grams of SiO_2 react with excess carbon according to the reaction below? ΔH^o for the reaction is +624.7 kJ.

$$SiO_2(s) + 3C(s) \rightarrow SiC(s) + 2CO(g)$$

a) 208 kJ
c) 5.06 kJ
b) 10.4 kJ
d) 31.2 kJ

15. The standard heat of combustion (ΔH^o) of ethanol is – 1372 kJ/mol ethanol. How much heat is released when a 20.0 g sample burns?

a) 68.6 kJ
b) 29.8 kJ
c) 3.16×10^3 kJ
d) 595 kJ

16. When one mole of methane burns in oxygen, 882 kJ/mol of energy is released. If 15.0 g of methane is burned, how much heat is released?

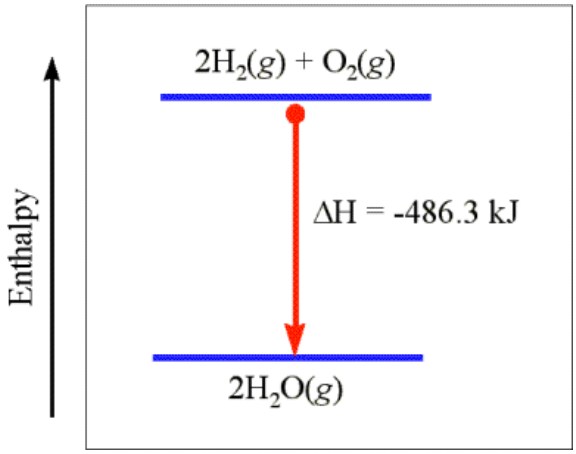
a) 55.0 kJ
b) 824 kJ
c) 58.8 kJ
d) 944 kJ

17. Given the following thermochemical equation: $2\ P\ (s) + 3\ Br_2\ (l) \rightarrow 2\ PBr_3\ (s) \quad \Delta H^o = 153$ kJ
How much energy must be added to allow the production of 7.12 grams of PBr_3?

a) 4.02 kJ
b) 21.5 kJ
c) 2.01 kJ
d) 10.7 kJ

18. Which thermochemical equation corresponds to the enthalpy diagram shown to the right?

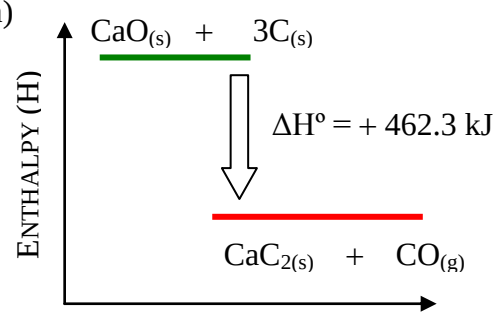
a) $2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g) + 486.3$ kJ
b) $2\ H_2\ (g) + O_2\ (g) + 486.3$ kJ $\rightarrow 2\ H_2O\ (g)$
c) $2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O\ (g) - 486.3$ kJ
d) $2\ H_2\ (g) + O_2\ (g) - 486.3$ kJ $\rightarrow 2\ H_2O\ (g)$



19. Which is the correct enthalpy level diagram for the reaction:

$$CaO_{(s)} + 3C_{(s)} + 462.3\ kJ \rightarrow CaC_{2(s)} + CO_{(g)}$$

a)



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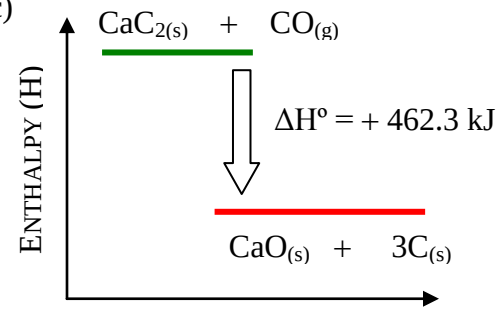

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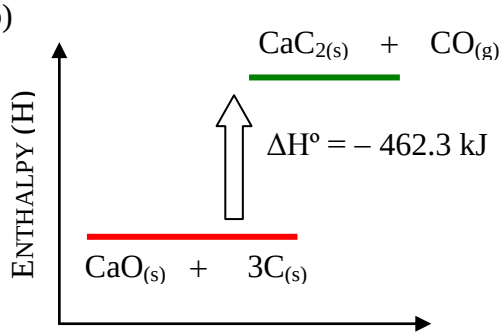
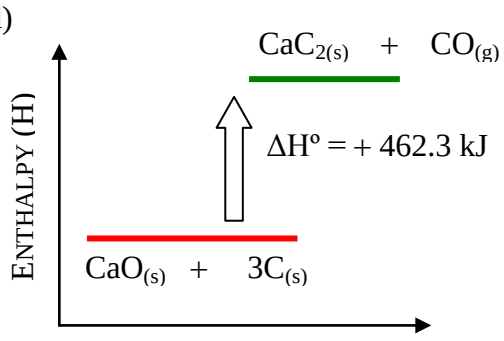


d)



20. Given the following thermochemical equation

$2\ C_2H_3Br\ (g) + 5\ O_2\ (g) \rightarrow 4\ CO_2\ (g) + 2\ H_2O\ (g) + 2\ HBr\ (g) \qquad \Delta H^o = 1150.\ kJ$

What is the change in energy accompanying the production of 1.500 moles of $CO_2(g)$?

a) 1725 kJ
b) 766.7 kJ
c) 431.3 kJ
d) 9.799 kJ

C. Calorimetry Questions:

- you can recognize these problems because they give data about a temperature change
- identify the substance that is changing temperature. For that substance, use its specific heat capacity (c) and mass along with the temperature change to calculate Q
- memorize the specific heat capacity for water = 4.184 J/g ^oC
- know the assumptions that are made when doing calorimetry calculations

21. A sample of water with a mass of 210.5 g undergoes a temperature change from 40.83^{o}C to 98.73 ^{o}C. What is the heat change in kilojoules?

a) 50.99 kJ
b) 242.3 kJ
c) –12.19 kJ
d) + 12.19 kJ

22. When 1.75 g of $CaCl_2$ dissolves in 125 g of water in a coffee-cup calorimeter, the temperature increases by 2.44ºC. What is the heat change per mole of $CaCl_2$ dissolved? Assume that all the heat is absorbed by the water.

a) –11.3 kJ/mol of $CaCl_2$
b) –1.13 kJ/mol of $CaCl_2$
c) –729 kJ/mol of $CaCl_2$
d) –80.9 kJ/mol of $CaCl_2$

23. The specific heat capacity of diamond is 0.5050 J/gºC. How much energy is required to heat 25.0 g of diamond from 10.5ºC to 15.6ºC?

a) 64.4 J
b) 269 J
c) 533 J
d) 2068 J

24. 2.50 g of hydrogen gas is heated from 17.0ºC to 23.0ºC. The specific heat capacity of hydrogen is 14.267 J/gºC. How much energy is absorbed?

a) 2.14×10^2 J
b) 0.214 J
c) 2.14×10^2 kJ
d) 0.00214 kJ

25. A 20.0 g sample of aluminum is cooled by 7.50ºC. The specific heat capacity of aluminum is 0.900 J/gºC. What is the energy change for this sample?

a) 135 kJ
b) 565 J
c) 135 J
d) 628 J

26. 5.50 g of sodium hydroxide is dissolved in 175 mL of water. Using a coffee-cup calorimeter, the temperature change of the water is measured to be +2.10°C. The specific heat capacity of water is 4.184 J/g°C. What is the thermochemical equation for this process?

a) $NaOH_{(s)} \rightarrow NaOH_{(aq)} + 1.54\ kJ$
b) $NaOH_{(s)} + 1.54\ kJ \rightarrow NaOH_{(aq)}$
c) $NaOH_{(s)} \rightarrow NaOH_{(aq)} + 11.2\ kJ$
d) $NaOH_{(s)} + 11.2\ kJ \rightarrow NaOH_{(aq)}$

27. A mass of 100.0 g of dilute hydrochloric acid is placed in a coffee cup calorimeter. The temperature of the solution is recorded to be 17.5°C. A piece of magnesium ribbon of mass 0.601 g is placed in the solution and the final temperature is recorded to be 39.6°C. Calculate the molar enthalpy change for this reaction: $Mg_{(s)} + 2\ HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$

a) + 15.4 kJ/mol of Mg
b) - 263 kJ/mol of Mg
c) - 374 kJ/mol of Mg
d) + 5.56 kJ/mol of Mg

D. Hess's Law Questions:

- you can recognize these problems because you will be given an equation with unknown ΔH (the target equation) and at least 2 other equations with their ΔH values
- on the test, you will be asked to show your work for one calculation

28. Calculate ΔH^o for the reaction: $Na_2O(s) + SO_3(g) \rightarrow Na_2SO_4(s)$ given the following:

(1) $Na(s) + H_2O(l) \rightarrow NaOH(s) + 1/2\ H_2(g)$ $\Delta H^o = -146$ kJ

(2) $Na_2SO_4(s) + H_2O(l) \rightarrow 2NaOH(s) + SO_3(g)$ $\Delta H^o = +418$ kJ

(3) $2Na_2O(s) + 2H_2(g) \rightarrow 4Na(s) + 2H_2O(l)$ $\Delta H^o = +259$ kJ

a) + 823 kJ
b) – 581 kJ
c) – 435 kJ
d) + 531 kJ

29. Given equations (1) and (2), calculate the enthalpy change for equation (3).

(1) $Pb_{(s)} + PbO_{2(s)} + 2\ SO_{3(g)} \rightarrow 2\ PbSO_{4(s)}$ $\Delta H^o = -775$ kJ

(2) $SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$ $\Delta H^o = -133$ kJ

(3) $Pb_{(s)} + PbO_{2(s)} + 2\ H_2SO_{4(aq)} \rightarrow 2\ PbSO_{4(s)} + 2\ H_2O_{(l)}$

a) – 908 kJ
b) – 642 kJ
c) – 509 kJ
d) + 642 kJ

30. Given that: $S(s) + O_2(g) \rightarrow SO_2(g)$ $\Delta H^o = -296.8$ kJ/mol

$2\ SO_3(g) \rightarrow 2\ SO_2(g) + O_2(g)$ $\Delta H^o = +197.8$ kJ/mol

Determine the enthalpy change of the reaction: $2\ S(s) + 3\ O_2(g) \rightarrow 2\ SO_3(g)$

a) – 99 kJ
b) – 495 kJ
c) + 495 kJ
d) – 791.4 kJ

31. Use the following reactions to calculate ΔH° for: $4\ HCl\ (g) + O_2(g) \rightarrow 2\ Cl_2(g) + 2\ H_2O(g)$

$H_2(g) + Cl_2\ (g) \rightarrow 2\ HCl(g)$ $\Delta H° = -185.0$ kJ

$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g)$ $\Delta H° = -483.7$ kJ

a) +113.7 kJ
b) –298.7 kJ
c) +298.7 kJ
d) –113.7 kJ

32. From the following enthalpies of reaction find ΔH° for: $2\ HCl(g) + F_2(g) \rightarrow 2\ HF(l) + Cl_2(g)$:

$4\ HCl(g) + O_2(g) \rightarrow 2\ H_2O(l) + 2\ Cl_2(g)$ $\Delta H = -148.4$ kJ

$1/2\ H_2(g) + 1/2\ F_2(g) \rightarrow HF(l)$ $\Delta H = -600.0$ kJ

$H_2(g) + 1/2\ O_2(g) \rightarrow H_2O(l)$ $\Delta H = -285.8$ kJ

a) –462.6 kJ
b) –840 kJ
c) –988.4 kJ
d) +1063 kJ

33. From the following data:

$CH_4\,(g) + 2O_2\,(g) \rightarrow CO_2\,(g) + 2H_2O\,(l)$ $\quad \Delta H^o = -890.\ kJ/mol$

$H_2O\,(l) \rightarrow H_2O\,(g)$ $\quad \Delta H^o = 44.0\ kJ/mol$

Calculate the enthalpy of the reaction:

$CH_4\,(g) + 2\,O_2\,(g) \rightarrow CO_2\,(g) + 2\,H_2O\,(g)$ $\quad \Delta H^o = ?$

a) – 802 kJ
b) – 846 kJ
c) – 890 kJ
d) – 934 kJ

34. Given equations (I), (II), and (III), calculate the standard enthalpy of formation of acetylene, C_2H_2, as shown in equation (IV).

(I) $C\,(s) + O_2\,(g) \rightarrow CO_2\,(g)$ $\quad \Delta H^o = -393.5\ kJ$

(II) $H_2\,(g) + \frac{1}{2}\,O_2\,(g) \rightarrow H_2O\,(l)$ $\quad \Delta H^o = -285.8\ kJ$

(III) $2\,C_2H_2\,(g) + 5\,O_2\,(g) \rightarrow 4\,CO_2\,(g) + 2\,H_2O\,(l)$ $\quad \Delta H^o = -2598.8\ kJ$

(IV) $2\,C\,(s) + H_2\,(g) \rightarrow C_2H_2\,(g)$

a) 253.6 kJ
b) 226.6 kJ
c) 1801 kJ
d) -3278 kJ

E. Standard Enthalpy (Heat) of Formation (ΔH_f) Questions:

- You will be given a data table with copies of the charts on page 597 and 599 for the test.
- Know the standard states of oxygen, carbon, phosphorus and sulfur
- Be able to write/recognize standard formation equations for compounds
- There are two kinds of calculations you should recognize:
  i) calculate the enthalpy change (ΔH) for a reaction using standard heats of formation (ΔH^o_f)
  ii) if you are given the heat of reaction for one equation (for example, heat of combustion (ΔH) for a substance), be able to use this along with standard heats of formation and "work backwards" to calculate the heat of formation for one of the substances in the initial equation you are given

35. Which thermochemical equation is the standard formation equation for $NH_4ClO_4(s)$?

a) $N_2(g) + 4\,H_2(g) + Cl_2(g) + 4\,O_2(g) \rightarrow 2\,NH_4ClO_4(s)$
b) $N(g) + 2\,H_2(g) + Cl_2(l) + 2\,O_2(g) \rightarrow NH_4ClO_4(s)$
c) $1/2\,N_2(g) + 2\,H_2(g) + 1/2\,Cl_2(g) + 2\,O_2(g) \rightarrow NH_4ClO_4(s)$
d) $N(g) + 4\,H(g) + Cl(g) + 4\,O(g) \rightarrow NH_4ClO_4(s)$

36. For which of the following is ΔH^o_f zero?

a) $N_2(g)$
b) $O_3\,(g)$
c) $S_8\,(s)$
d) $He_2\,(g)$

37. Which of the following is a formation reaction?

a) $PCl_3(g) + \frac{1}{2}\,O_2(g) \rightarrow POCl_3(g)$
b) $N_2O(g) + \frac{1}{2}\,O_2(g) \rightarrow 2\,NO(g)$
c) $Al(s) + 3/2\,H_2(g) + 3/2\,O_2(g) \rightarrow Al(OH)_3(s)$
d) all of the above are formation equations

38. Which of the following is **NOT** a formation reaction?

a) $1/2\,H_2(g) + 1/2\,Br_2(l) \rightarrow HBr(g)$
b) $2Al(s) + 3/2\,O_2(g) \rightarrow Al_2O_3(s)$
c) $Ca(s) + 1/2\,O_2(g) \rightarrow CaO(s)$
d) $H_2O(l) + SO_3(l) \rightarrow H_2SO_4(l)$

39. Using standard enthalpies of formation, calculate the enthalpy of the reaction:

$$H_2SO_{4(l)} + 2\ HCl_{(g)} \rightarrow Cl_{2(g)} + SO_{2(g)} + 2\ H_2O_{(l)}$$

a) 904 kJ
b) -724 kJ
c) -130 kJ
d) 130 kJ

40. Using standard enthalpies of formation, calculate the enthalpy of the reaction:

$$2\ H_2S_{(g)} + 3\ O_{2(g)} \rightarrow 2\ SO_{2(g)} + 2\ H_2O_{(g)}$$

a) - 2794 kJ
b) - 1036 kJ
c) - 1077 kJ
d) - 1124 kJ

41. Use standard heats of formation to calculate $\Delta H°$ for the following reaction:

$$Fe_3O_4(s) + CO(g) \rightarrow 3\ FeO(s) + CO_2(g)$$

a) 54.1 kJ
b) –202 kJ
c) 19.4 kJ
d) –50.0 kJ

42. Liquid butane, C_4H_{10}, burns to produce water vapour and carbon dioxide. The reaction produces 2662.8 kJ of energy per mole of butane burned. Use this information, along with standard heats of formation, to calculate the $\Delta H°_f$ (the heat of formation) for butane.

a) 120.2 kJ
b) -120.2 kJ
c) + 5446 kJ
d) - 5446 kJ

43. Using molar enthalpies of formation, determine the heat of reaction for the combustion of 1.000 mole of methanol.

$$CH_3OH(l) + 3/2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(v)$$

a) – 637.9 kJ
b) – 440.1 kJ
c) – 874.5 kJ
d) – 396.1 kJ

44. Use standard heats of formation to calculate the enthalpy change for the reaction:

$$2\ NH_3(g) + 3\ O_2(g) + 2\ CH_4(g) \rightarrow 2\ HCN(g) + 6\ H_2O(g)$$

a) –939.6 kJ
b) +1123 kJ
c) –1204 kJ
d) +135 kJ

45. Calculate the heat of formation for liquid pentane, C_5H_{12}, given that the combustion of pentane produces 3509.1 kJ/mol (the state of the water produced is vapour).

a) 171.2 kJ/mol
b) –171.2 kJ/mol
c) -90.8 kJ/mol
d) +90.8 kJ/mol

F. Bond Energy Questions

46. Use bond energies to estimate the heat of reaction ($\Delta H°$) for:

$$CH_4\ (g) + 2\ Cl_2\ (g) \rightarrow CH_2Cl_2\ (g) + 2\ HCl\ (g)$$

a) -496 kJ
b) -857 kJ
c) -1478 kJ
d) -586 kJ

47. Use bond energies to estimate the heat of reaction (ΔH°) for:

$$H_2\,(g) + CO_2\,(g) \rightarrow HCOOH\,(l)$$

a) 25.0 kJ
b) –4.00 kJ
c) +301 kJ
d) +272 kJ

48. Use bond energies to estimate the heat of reaction (ΔH°) for:

$$4\,HCl(g) + O_2(g) \rightarrow 2\,H_2O(l) + 2\,Cl_2(g)$$

a) +820. kJ
b) -100. kJ
c) -394 kJ
d) +526 kJ

G. Comparing Energy in Physical, chemical and Nuclear Changes

49. Which involves the largest energy change?
a) 1 mol of water boiling
b) 1 tonne of TNT exploding
c) the daily electrical output of the hydroelectric generating stations at Niagara Falls
d) the output of all the CANDU nuclear reactors in North America

50. Which process **produces** the most energy?
a) cooking
b) melting a glacier
c) dissolving acid in water
d) the sun shining

You will be asked to show your work for several calculations. For example:

1. In an experiment, 5.260 g of potassium hydroxide is mixed with a dilute solution of hydrochloric acid. A neutralization (double displacement) reaction occurs. The hydrochloric acid is in excess. The following date are obtained:

Initial temperature of hydrochloric acid	24.5 ºC
Volume of hydrochloric acid	200.0 mL
Final temperature of solution after mixing	31.4 ºC

Calculate the molar heat of reaction (Δ*H*) per mole of potassium hydroxide.

2. An experiment was conducted using the reaction: $HNO_{3(aq)} + KOH_{(aq)} \rightarrow H_2O_{(l)} + KNO_{3(aq)}$

The following data were collected:

volume of 1.3-M HNO_3	55.0 mL
initial temperature of HNO_3	23.5 ^oC
volume of 1.3-M KOH	60.0 mL
initial temperature of KOH	23.5 ^oC
final temperature after mixing	31.8 ^oC

Calculate the heat of reaction, ΔH, expressed in kJ per mole of HNO_3.

3. Find ΔH for $3N_2H_4\,(l) + 4\,C\ell F_3\,(g) \rightarrow 3\,N_2\,(g) + 12\,HF\,(g) + 2\,C\ell_2\,(g)$

Given: (1) $2\,C\ell F_3\,(g) + 2\,NH_3\,(g) \rightarrow N_2\,(g) + 6\,HF\,(g) + C\ell_2\,(g)$ $\Delta H = -1196$ kJ

(2) $N_2H_4\,(l) + O_{2(g)} \rightarrow N_2\,(g) + 2\,H_2O\,(l)$ $\Delta H = -622.0$ kJ

(3) $4\,NH_3\,(g) + 3\,O_2\,(g) \rightarrow 2\,N_2\,(g) + 6\,H_2O\,(l)$ $\Delta H = -1530.$ kJ

4. Use the following equations to determine the heat of formation of solid aluminum chloride.

(1) $2\,Al_{(s)} + 6\,HCl_{(aq)} \rightarrow 2\,AlCl_{3(aq)} + 3\,H_{2(g)}$ $\Delta H = -1049$ kJ

(2) $H_{2(g)} + Cl_{2(g)} \rightarrow 2\,HCl_{(g)}$ $\Delta H = -184$ kJ

(3) $HCl_{(g)} \rightarrow HCl_{(aq)}$ $\Delta H = -75$ kJ

(4) $AlCl_{3(s)} \rightarrow AlCl_{3(aq)}$ $\Delta H = -326$ kJ

5. Find ΔH for: $Zn_{(s)} + 2\,HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$

Given: (1) $Zn_{(s)} + Cl_{2(g)} \rightarrow ZnCl_{2(s)}$ $\Delta H = -41.5$ kJ

(2) $H_{2(g)} + Cl_{2(g)} \rightarrow 2\,HCl_{(g)}$ $\Delta H = -184.4$ kJ

(3) $ZnCl_{2(s)} \rightarrow ZnCl_{2(aq)}$ $\Delta H = -71.1$ kJ

(4) $HCl_{(g)} \rightarrow HCl_{(aq)}$ $\Delta H = -74.8$ kJ

6. The $\Delta H°_f$ of $Mg(NO_3)_{2(aq)} = -875.0$ kJ/mol. Use this value and the heats of formation of the compounds on page 597 to calculate $\Delta H°$ for the equation below:

$$2\,HNO_{3(l)} + Mg(OH)_{2(s)} \rightarrow Mg(NO_3)_{2(aq)} + 2\,H_2O_{(l)}$$

7. Liquid butane, C_4H_{10}, burns to produce water vapour and carbon dioxide. The ΔH for the reaction is –2662.8 kJ/mol butane burned. Use this value and $\Delta H°_f$ values on page 597 to calculate the heat of formation ($\Delta H°_f$) of butane.

8. Use bond energies to estimate the enthalpy change (ΔH) for the reaction when solid nitrogen triiodide (NI_3, a contact explosive) decomposes to produce nitrogen gas and pure iodine vapour:

$$2\,NI_{3\,(s)} \rightarrow N_{2(g)} + 3\,I_{2\,(v)}$$

Express your answer in kJ/mol of NI_3.

9. Use bond energies to estimate ΔH for the reaction:

$$C_2H_4 + Cl_2 \rightarrow C_2H_4Cl_2$$

Express your answer in kJ/mol of C_2H_4.