# CHAPTER 6
# THERMOCHEMISTRY

6-1. The standard state of an element or compound is determined at a pressure of _____ and a temperature of _____.
(a) 760 atm, 0 °C (b) 1 mmHg, 273 °C
(c) 760 atm, 0 K (d) 1 atm, 298 K

6-2. What name is used for the amount of heat required to raise the temperature of any specific substance by one degree Celsius?
(a) heat capacity (b) standard temperature
(c) heat of reaction (d) state function

6-3. What is the value of the standard enthalpy of formation for any element under standard conditions?
(a) 273 J/mol (b) 0.24 J/mol
(c) 4.18 J/mol (d) 0 J/mol

6-4. One Joule (1.00 J) is equivalent to _____calories.
(a) 273 cal (b) 4.18 cal
(c) 0.24 cal (d) 0.00 cal

6-5. The specific heat of iron is 0.451 J/g • K. What is the molar specific heat of iron?
(a) 0.451 J/mol • K (b) 26.0 J/mol • K
(c) 25.2 J/mol • K (d) 55.85 J/mol • K

6-6. Which of the following is a state function, that is, a change in this quantity depends only on the initial and final states of the system being discussed?
(a) enthalpy (b) work
(c) heat (d) power

6-7. Which of the following is a mathematical statement of the First Law of Thermodynamics?
(a) $\Delta E = E_{final} - E_{initial}$ (b) $E = mc^2$
(c) $E = h\nu$ (d) $\Delta E = q + w$

6-8. What is the name given to the type of a chemical reaction characterized by the release of heat energy?
(a) endothermic (b) nonspontaneous
(c) exothermic (d) adiabatic

6-9. The enthalpy change is the heat absorbed or given off during a chemical reaction that occurs at constant _____.
(a) temperature (b) reaction rate
(c) volume (d) pressure

6-10. What is the sign of the enthalpy change for an endothermic reaction?
(a) Positive
(b) Can't be determined from the information given.
(c) Negative
(d) Depends on the temperature.

6-11. Based on everyday experience, which of the following substances has the smallest specific heat capacity, that is, which one heats up most readily?
(a) water (b) copper
(c) wood (d) cement

6-12. What is the latent heat of fusion of lead, if 6.30 kilojoules of heat are required to convert 255 grams of solid lead at its melting point into a liquid?
(a) 0.0250 J/g (b) 1.61 J/g
(c) 24.7 J/g (d) 40.5 J/g

6-13. How many kilojoules of heat are required to heat 95.2 grams of ice from -10.0 °C to the melting point and melt all of the ice? (The latent heat of fusion of water is 333 J/g.)
(a) 3.98 kJ (b) 31.7 kJ
(c) 35.7 kJ (d) 39.7 kJ

6-14. How many joules of heat are required to heat 1.00 g of lead from 25 °C to the melting point (327 °C) and melt all of it? (The specific heat capacity of lead is 0.159 J/g • K and it requires 24.7 J/g to convert lead from the solid to the liquid state.)
(a) 2.47 J (b) 39.4 J
(c) 48.0 J (d) 72.7 J

6-15. When 221 grams of water at a temperature of 25.0 °C is mixed with an unknown mass of water at a temperature of 57.0 °C the final temperature of the resulting mixture is 33.1 °C. What was the mass of the second sample of water?
(a) 29.5 g (b) 67.0 g
(c) 74.9 g (d) 131 g

6-16. When 86.7 grams of water at a temperature of 73.0 °C is mixed with an unknown mass of water at a temperature of 22.3 °C the final temperature of the resulting mixture is 61.7 °C. What was the mass of the second sample of water?
(a) 24.9 g (b) 48.2 g
(c) 302 g (d) 419 g

6-17. When 108 grams of water at a temperature of 22.5 °C is mixed with 65.1 grams of water at an unknown temperature, the final temperature of the resulting mixture is 47.9 °C. What was the temperature of the other sample of water?
(a) 18.9 °C (b) 67.0 °C
(c) 79.7 °C (d) 90.0 °C

6-18. When a piece of copper, at a temperature of 256 °C, is added to 255 grams of water, at a temperature of 20.0 °C, the final temperature of the resulting mixture is 24.0 °C. If the heat capacity of copper is 0.385 J/g • K, what was the mass of the copper?

(a) 0.0405 g (b) 47.7 g
(c) 99.2 g (d) 219 g

6-19. When 182 grams of gold is added to 22.1 grams of water at a temperature of 25.0 °C the final temperature of the resulting mixture is 27.5 °C. If the heat capacity of gold is 0.129 J/g • K, what was the initial temperature of the gold sample?

(a) 19.3 ˚C (b) 24.4 ˚C
(c) 37.4 ˚C (d) 41.4 ˚C

6-20. Calculate the amount of heat required to heat 357 grams of ethylene glycol (antifreeze) from 0 °C to 110 °C. The specific heat of ethylene glycol is 2.42 J/g • K.

(a) 16.2 kJ (b) 39.3 kJ
(c) 71.5 kJ (d) 95.0 kJ

6-21. Calculate the specific heat of Freon-12, $CCl_2F_2$, if it requires 2930 joules of heat to raise the temperature of 89.1 grams of this gas by 55.0 °C.

(a) 0.00600 J/g • K (b) 0.598 J/g • K
(c) 1.67 J/g • K (d) 2.83 J/g • K

6-22. Calculate the specific heat of a certain unknown metal, if it requires 195 joules of heat to raise the temperature of 12.1 grams of this metal by 34.6 °C.

(a) 0.451 J/g • K (b) 0.335 J/g • K
(c) 0.714 J/g • K (d) 0.816 J/g • K

6-23. If 0.750 grams of magnesium oxide is placed in a coffee-cup calorimeter and then 100.0 mL of 1.00 M HCl is added, the temperature of the HCl solution increases from 22.8 °C to 28.7 °C. Based on this information, calculate the enthalpy change for this reaction per mol of MgO. You may assume that the specific heat of the solution is 4.20 J/g • K and the density of the HCl solution is 1.00 g/mL.

(a) -2.54 kJ/mol (b) -29.8 kJ/mol
(c) -65.3 kJ/mol (d) -134 kJ/mol

6-24. When a piece of aluminum weighing 35.7 grams, and at a temperature of 81.9 °C, is placed in a calorimeter containing 75.0 grams of water at 24.9 °C, the temperature increases to 28.3 °C. If the specific heat of the water is 4.18 J/g • K and the specific heat of the aluminum is 0.902 J/g • K, what is the specific heat of the calorimeter?

(a) 11.6 J/K (b) 194 J/K
(c) 496 J/K (d) 2290 J/K

6-25. When a piece of unknown metal weighing 24.4 grams, and at a temperature of 119.3 °C, is placed in a calorimeter containing 51.0 grams of water at 19.6 °C, the temperature increases to 20.8 °C. If the specific heat of the water is 4.18 J/g • K and the specific heat of the calorimeter is 159 J/K, what is the specific heat of the unknown metal?

(a) 0.128 J/g • K (b) 0.186 J/g • K
(c) 0.723 J/g • K (d) 1.12 J/g • K

6-26. When a piece of unknown metal weighing 44.1 grams, and at a temperature of 99.0 °C, is placed in a calorimeter containing 86.1 grams of water at 20.6 °C, the temperature increases to 22.3 °C. If the specific heat of the water is 4.18 J/g • K and the specific heat of the calorimeter is 247 J/K, what is the specific heat of the unknown metal?

(a) 0.0567 J/g • K (b) 0.111 J/g • K
(c) 0.305 J/g • K (d) 0.490 J/g • K

6-27. The standard molar enthalpy of combustion for propane is -2044 kilojoules.

$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(\ell)$

What is the standard enthalpy change for the combustion of 3.000 mols of propane?

$3\ C_3H_8(g) + 15\ O_2(g) \rightarrow 9\ CO_2(g) + 12\ H_2O(\ell)$

(a) -6132 kJ (b) -4088 kJ
(c) -2044 kJ (d) +2044 kJ

6-28. The standard molar enthalpy of combustion for ethanol, $C_2H_5OH$, is -1409 kilojoules.

$C_2H_5OH(g) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(\ell)$

What is the standard enthalpy change for the following process?

$4\ CO_2(g) + 6\ H_2O(\ell) \rightarrow 2\ C_2H_5OH(g) + 6\ O_2(g)$

(a) -1409 kJ (b) -2818 kJ
(c) +1409 kJ (d) +2818 kJ

6-29. Calculate the amount of heat required to convert one mol of carbon tetrachloride from a liquid to a vapor, given that the standard molar enthalpy of formation for $CCl_4(\ell)$ is -135.4 kJ/mol and the standard molar enthalpy of formation for $CCl_4(g)$ is -103.1 kJ/mol.

(a) +103.1 kJ/mol (b) +32.3 kJ/mol
(c) -32.2 kJ/mol (d) -132.2 kJ/mol

6-30. What is the value of the molar enthalpy (or heat) of combustion of ethane, a simple hydrocarbon having the formula $C_2H_6$, if the combustion of 3.01 grams of this gas at constant pressure releases 8.47 kilojoules of heat?

(a) -0.847 kJ/mol (b) -8.47 kJ/mol
(c) -84.7 kJ/mol (d) -847 kJ/mol

6-31. The molar enthalpy (or heat) of combustion of ethanol, a simple alcohol having the formula $C_2H_5OH$, is -277.7 kJ/mol. How many kilojoules of heat will be released by the combustion of 9.22 grams of this liquid at constant pressure?

(a) 11.8 kJ (b) 27.8 kJ
(c) 32.9 kJ (d) 55.5 kJ

6-32. Calculate the standard enthalpy change for the reaction

$C_2H_2(g) + H_2(g) \rightarrow C_2H_4(g)$

based on the following standard enthalpies of formation: $\Delta H^\circ_f[C_2H_2(g)] = +226.7$ kJ/mol and $\Delta H^\circ_f[C_2H_4(g)] = +52.3$ kJ/mol

(a) -56.4 kJ (b) -174.4 kJ
(c) -279.0 kJ (d) -321.1 kJ

6-33. Calculate the standard enthalpy of combustion for the reaction

$SiH_4(g) + 2\ O_2(g) \rightarrow SiO_2(g) + 2\ H_2O(g)$

based on the following standard enthalpies of formation: $\Delta H^\circ_f[SiH_4(g)] = +34.3$ kJ/mol; $\Delta H^\circ_f[SiO_2(g)] = -910.9$ kJ/mol; and $\Delta H^\circ_f[H_2O(g)] = -241.8$ kJ/mol.

(a) -1187.0 kJ (b) -1360.2 kJ
(c) -1428.8 kJ (d) -2218.7 kJ

6-34. Calculate the standard molar enthalpy of formation for $Na_2O(s)$, given that the standard enthalpy of formation for $Na_2O_2(s)$ is -505 kJ/mol and the enthalpy change for the following reaction

$Na_2O(s) + 1/2\ O_2(g) \rightarrow Na_2O_2(s)$

is -89.0 kJ/mol.

(a) 594 kJ/mol (b) 416 kJ/mol
(c) -416 kJ/mol (d) -594 kJ/mol

6-35. Calculate the standard enthalpy of combustion for acetylene, $C_2H_2$,

$C_2H_2(g) + 5/2\ O_2(g) \rightarrow 2\ CO_2(g) + H_2O(g)$

based on the following standard enthalpies of formation: $\Delta H^\circ_f[C_2H_2(g)] = +226.7$ kJ/mol; $\Delta H^\circ_f[CO_2(g)] = -393.5$ kJ/mol; and $\Delta H^\circ_f[H_2O(g)] = -241.8$ kJ/mol.

(a) -1255.5 kJ (b) -862.0 kJ
(c) -408.6 kJ (d) +408.6 kJ

6-36. Calculate the standard molar enthalpy of combustion for ethene, $C_2H_4$,

$C_2H_4(g) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 2\ H_2O(g)$

based on the following standard enthalpies of formation: $\Delta H^\circ_f[C_2H_4(g)] = +52.26$ kJ/mol; $\Delta H^\circ_f[CO_2(g)] = -393.5$ kJ/mol; and $\Delta H^\circ_f[H_2O(g)] = -241.8$ kJ/mol.

(a) -204.3 kJ (b) -583.8 kJ
(c) -687.6 kJ (d) -1322.9 kJ

6-37. Calculate the standard enthalpy of combustion for propane, $C_3H_8$,

$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$

based on the following standard enthalpies of formation: $\Delta H^\circ_f[C_3H_8(g)] = -103.8$ kJ/mol; $\Delta H^\circ_f[CO_2(g)] = -393.5$ kJ/mol; and $\Delta H^\circ_f[H_2O(g)] = -241.8$ kJ/mol.

(a) -2252.0 kJ (b) -2043.9 kJ
(c) -109.5 kJ (d) +2043.9 kJ

6-38. Calculate the standard enthalpy of reaction for the process

$2\ NO_2(g) + 7\ H_2(g) \rightarrow 2\ NH_3(g) + 4\ H_2O(g)$

based on the following standard enthalpies of formation: $\Delta H^\circ_f[NH_3(g)] = -46.1$ kJ/mol; $\Delta H^\circ_f[NO_2(g)] = +33.2$ kJ/mol; and $\Delta H^\circ_f[H_2O(g)] = -241.8$ kJ/mol.

(a) -1125.8 kJ (b) -993.1 kJ
(c) -808.4 kJ (d) -254.7 kJ

6-39. The standard molar enthalpy change is -802.3 kJ for the combustion of methane gas.

$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$

Calculate the standard molar enthalpy of formation for methane based on the following standard enthalpies of formation: $\Delta H^\circ_f[CO_2(g)] = -393.5$ kJ/mol and $\Delta H^\circ_f[H_2O(g)] = -241.8$ kJ/mol.

(a) -1679 kJ/mol (b) -125.4 kJ/mol
(c) -74.8 kJ/mol (d) +892.4 kJ/mol

6-40. The standard molar enthalpy change is -3135 kJ for the combustion of benzene.

$C_6H_6(\ell) + 15/2\ O_2(g) \rightarrow 6\ CO_2(g) + 3\ H_2O(g)$

Calculate the standard molar enthalpy of formation for benzene based on the following standard enthalpies of formation: $\Delta H^\circ_f[CO_2(g)] = -393.5$ kJ/mol and $\Delta H^\circ_f[H_2O(g)] = -241.8$ kJ/mol.

(a) -7670 kJ/mol (b) -3230 kJ/mol
(c) -783 kJ/mol (d) +49 kJ/mol

6-41. The standard molar enthalpy change is -905.2 kJ for the oxidation of ammonia.

$4\ NH_3(g) + 5\ O_2(g) \rightarrow 4\ NO(g) + 6\ H_2O(g)$

Calculate the standard molar enthalpy of formation for ammonia based on the following standard enthalpies of formation: $\Delta H^\circ_f[NO(g)] = +90.3$ kJ/mol; and $\Delta H^\circ_f[H_2O(g)] = -241.8$ kJ/mol.

(a) -46.1 kJ/mol (b) -92.2 kJ/mol
(c) -226.7 kJ/mol (d) -498.8 kJ/mol

6-42. The standard molar enthalpy change is -1277.3 kJ for the combustion of ethanol.

$C_2H_5OH(g) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(g)$

Calculate the standard molar enthalpy of formation for ethanol based on the following standard enthalpies of formation: $\Delta H^\circ_f[CO_2(g)] = -393.5$ kJ/mol and $\Delta H^\circ_f[H_2O(g)] = -241.8$ kJ/mol.

(a) -122.9 kJ/mol (b) -235.1 kJ/mol
(c) -642.7 kJ/mol (d) +642.0 kJ/mol

6-43. Calculate the enthalpy of vaporization for titanium(IV) chloride

$TiCl_4(\ell) \rightarrow TiCl_4(g)$

given the following enthalpies of reaction:

$Ti(s) + 2\ Cl_2(g) \rightarrow TiCl_4(\ell)$ $\Delta H^o = -804.2$ kJ

$TiCl_4(g) \rightarrow 2\ Cl_2(g) + Ti(s)$ $\Delta H^o = 763.2$ kJ

(a) -80.4 kJ (b) +41.0 kJ
(c) +80.4 kJ (d) +127.3 kJ

6-44. Calculate the standard molar enthalpy of formation of $FeCl_2(s)$ using the following standard enthalpies of reaction:

$1/2\ Cl_2(g) + FeCl_2(s) \rightarrow FeCl_3(s)$ $\Delta H^o = -57.7$ kJ

$Fe(s) + 3/2\ Cl_2(g) \rightarrow FeCl_3(s)$ $\Delta H^o = -399.5$ kJ

(a) -57.7 kJ/mol (b) -284.1 kJ/mol
(c) -341.8 kJ/mol (d) -457.2 kJ/mol

6-45. Calculate the standard enthalpy change of reaction for the process

$H_2O_2(\ell) \rightarrow 1/2\ O_2(g) + H_2O(g)$

using the following reactions:

$H_2(g) + O_2(g) \rightarrow H_2O_2(\ell)$ $\Delta H^o = -187.8$ kJ

$H_2O(g) \rightarrow H_2(g) + 1/2\ O_2(g)$ $\Delta H^o = +241.8$ kJ

(a) -54.0 kJ (b) -98.4 kJ
(c) -385.2 kJ (d) -429.6 kJ

6-46. Calculate the standard enthalpy change of reaction for the process

$CH_4(g) + 3\ Cl_2(g) \rightarrow CHCl_3(g) + 3\ HCl(g)$

using the following reactions:

$HCl(g) \rightarrow 1/2\ H_2(g) + 1/2\ Cl_2(g)$ $\Delta H^o = +92.3$ kJ

$C(s) + 2\ H_2(g) \rightarrow CH_4(g)$ $\Delta H^o = -74.8$ kJ

$C(s) + 1/2\ H_2(g) + 3/2\ Cl_2(g) \rightarrow CHCl_3(g)$ $\Delta H^o = -103.1$ kJ

(a) -120.6 kJ (b) -212.9 kJ
(c) -305.2 kJ (d) -454.8 kJ

6-47. Calculate the standard enthalpy of reaction for the process

$NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$

using the following reactions:

$2\ HCl(g) \rightarrow H_2(g) + Cl_2(g)$ $\Delta H^o = +184.6$ kJ

$2\ H_2(g) + 1/2\ N_2(g) + 1/2\ Cl_2(g) \rightarrow NH_4Cl(s)$ $\Delta H^o = -314.4$ kJ

$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$ $\Delta H^o = -92.2$ kJ

(a) -175.7 kJ (b) -222 kJ
(c) -406.8 kJ (d) -591.2 kJ

6-48. Using the following reactions

$C(s) + 2\ Cl_2(g) \rightarrow CCl_4(\ell)$ $\Delta H^o = -135.4$ kJ

$H_2(g) + Cl_2(g) \rightarrow 2\ HCl(s)$ $\Delta H^o = -184.6$ kJ

$CH_4(g) \rightarrow 2\ H_2(g) + C(s)$ $\Delta H^o = +74.8$ kJ

calculate the standard enthalpy of reaction for the process

$CH_4(g) + 4\ Cl_2(g) \rightarrow CCl_4(\ell) + 4\ HCl(g)$

(a) -152.9 kJ (b) -245.2 kJ
(c) -337.5 kJ (d) -429.8 kJ

6-49. Cyanamide, $CH_2N_2$, is a weak acid that is sometimes used as a fertilizer. Calculate the standard enthalpy of formation for cyanamide, given the following standard enthalpies of reaction:

$CH_2N_2(s) + 3/2\ O_2(g) \rightarrow CO_2(g) + H_2O(\ell) + N_2(g)$ $\Delta H_1 = -741.4$ kJ/mol

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H_2 = -393.5$

$H_2(g) + 1/2\ O_2(g) \rightarrow H_2O(\ell)$ $\Delta H_3 = -285.8$

(a) +62.1 kJ/mol (b) -633 kJ/mol
(c) -849 kJ/mol (d) -1420 kJ/mol

6-50. The combination of coke and steam produces a mixture called coal gas, which can be used as a fuel or as a starting material for other reactions. The equation for the production of coal gas is

$2\ C(s) + 2\ H_2O(g) \rightarrow CH_4(g) + CO_2(g)$

Determine the standard enthalpy change for this reaction based on the following standard enthalpies of reaction:

$C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$ $\Delta H^o = +131.3$ kJ

$CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g)$ $\Delta H^o = -41.2$ kJ

$CH_4(g) + H_2O(g) \rightarrow 3\ H_2(g) + CO(g)$ $\Delta H^o = +206.1$ kJ

(a) -509.9 kJ (b) -97.7 kJ
(c) -25.7 kJ (d) +15.3 kJ

# ANSWERS — CHAPTER 6

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|---|---|---|---|---|---|
| 1. | d | 11. | b | 21. | b |
| 2. | a | 12. | c | 22. | a |
| 3. | d | 13. | c | 23. | d |
| 4. | c | 14. | d | 24. | b |
| 5. | c | 15. | c | 25. | b |
| 6. | a | 16. | a | 26. | c |
| 7. | d | 17. | d | 27. | a |
| 8. | c | 18. | b | 28. | d |
| 9. | d | 19. | c | 29. | b |
| 10. | a | 20. | d | 30. | c |
| 31. | d | 41. | a | | |
| 32. | b | 42. | b | | |
| 33. | c | 43. | b | | |
| 34. | c | 44. | c | | |
| 35. | a | 45. | a | | |
| 36. | d | 46. | c | | |
| 37. | b | 47. | a | | |
| 38. | a | 48. | d | | |
| 39. | c | 49. | a | | |
| 40. | d | 50. | d | | |