Chapter 6:
Thermochemistry

&

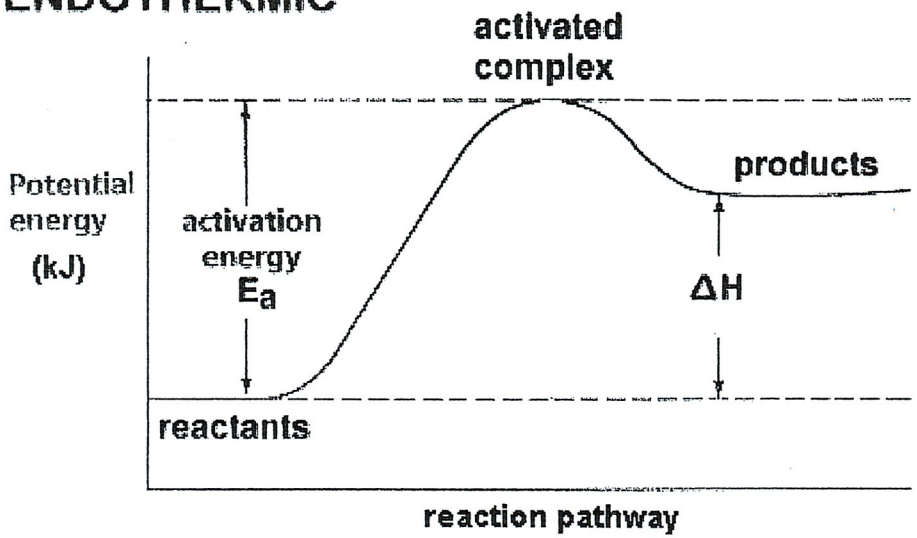
Gibbs Free Energy

Chapter 6

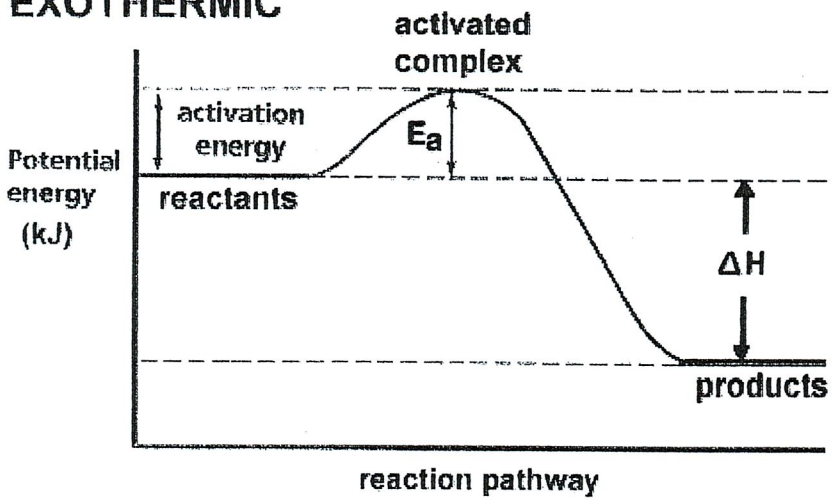
Thermochemistry

ΔH Enthalpy	ΔS Entropy	T	ΔG Free Energy	Spontaneity
-	+	Low High	- -	Always spontaneous
+	-	Low High	+ +	Never spontaneous
+	+	Low High	+ -	Not spon. at low T Spon. at high T
-	-	Low High	- +	Spon. At low T Not spon. At high T

ENDOTHERMIC



EXOTHERMIC



CHAPTER 8 QUESTIONS

MULTIPLE-CHOICE QUESTIONS

Questions 1–4

(A) Free energy change (ΔG)
(B) Entropy change (ΔS)
(C) Heat of vaporization
(D) Heat of fusion
(E) Heat capacity

1. If this has a negative value for a process, then the process occurs spontaneously.

2. This is a measure of how the disorder of a system is changing.

3. This is the energy given off when a substance condenses.

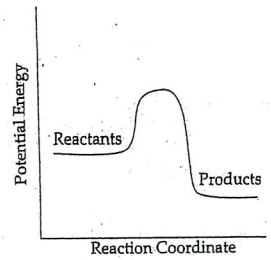
4. This is the energy taken in by a substance when it melts.

5. $2\,Al(s) + 3\,Cl_2(g) \rightarrow 2\,AlCl_3(s)$

The reaction above is not spontaneous under standard conditions, but becomes spontaneous as the temperature decreases toward absolute zero. Which of the following is true at standard conditions?

(A) ΔS and ΔH are both negative.
(B) ΔS and ΔH are both positive.
(C) ΔS is negative, and ΔH is positive.
(D) ΔS is positive, and ΔH is negative.
(E) ΔS and ΔH are both equal to zero.

6.



Which of the following is true of the reaction shown in the diagram above?

(A) The reaction is endothermic because the reactants are at a higher energy level than the products.
(B) The reaction is endothermic because the reactants are at a lower energy level than the products.
(C) The reaction is exothermic because the reactants are at a higher energy level than the products.
(D) The reaction is exothermic because the reactants are at a lower energy level than the products.
(E) The reaction is endothermic because the reactants are at the same energy level as the products.

7. $2\,H_2(g) + O_2(g) \rightarrow 2\,H_2O(g)$

Based on the information given in the table below, what is $\Delta H°$ for the above reaction?

Bond	Average bond energy (kJ/mol)
H–H	500
O=O	500
O–H	500

(A) –2,000 kJ
(B) –1,500 kJ
(C) –500 kJ
(D) +1,000 kJ
(E) +2,000 kJ

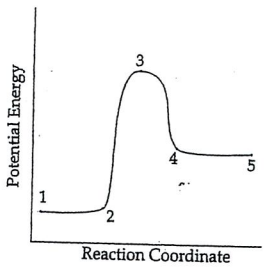
8. Which of the following is true of a reaction that is spontaneous at 298 K but becomes nonspontaneous at a higher temperature?

(A) $\Delta S°$ and $\Delta H°$ are both negative.
(B) $\Delta S°$ and $\Delta H°$ are both positive.
(C) $\Delta S°$ is negative, and $\Delta H°$ is positive.
(D) $\Delta S°$ is positive, and $\Delta H°$ is negative.
(E) $\Delta S°$ and $\Delta H°$ are both equal to zero.

9. Which of the following will be true when a pure substance in liquid phase freezes spontaneously?

(A) ΔG, ΔH, and ΔS are all positive.
(B) ΔG, ΔH, and ΔS are all negative.
(C) ΔG and ΔH are negative, but ΔS is positive.
(D) ΔG and ΔS are negative, but ΔH is positive.
(E) ΔS and ΔH are negative, but ΔG is positive.

10.



Which point on the graph shown above corresponds to activated complex or transition state?

(A) 1
(B) 2
(C) 3
(D) 4
(E) 5

11. $C(s) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H° = -390$ kJ/mol

$H_2(g) + \frac{1}{2}\,O_2(g) \rightarrow H_2O(l) \quad \Delta H° = -290$ kJ/mol

$2\,C(s) + H_2(g) \rightarrow C_2H_2(g) \quad \Delta H° = +230$ kJ/mol

Based on the information given above, what is $\Delta H°$ for the following reaction?

$$C_2H_2(g) + \frac{5}{2}\,O_2(g) \rightarrow 2\,CO_2(g) + H_2O(l)$$

(A) –1,300 kJ
(B) –1,070 kJ
(C) –840 kJ
(D) –780 kJ
(E) –680 kJ

3. $$N_2(g) + 3\,H_2(g) \rightleftharpoons 2\,NH_3(g)$$

The heat of formation, ΔH°_f, of $NH_3(g)$ is -46.2 kJ/mol. The free energy of formation, ΔG°_f, of $NH_3(g)$ is -16.7 kJ/mol.

(a) What are the values of ΔH° and ΔG° for the reaction?

(b) What is the value of the entropy change, ΔS°, for the reaction above at 298 K?

(c) As the temperature is increased, what is the effect on ΔG for the reaction? How does this affect the spontaneity of the reaction?

(d) At what temperature can N_2, H_2, and NH_3 gases be maintained together in equilibrium, each with a partial pressure of 1 atm?

Essays

4. $$2\,H_2(g) + O_2(g) \rightarrow 2\,H_2O(l)$$

The reaction above proceeds spontaneously from standard conditions at 298 K.

(a) Predict the sign of the entropy change, ΔS°, for the reaction. Explain.

(b) How would the value of ΔS° for the reaction change if the product of the reaction was $H_2O(g)$?

(c) What is the sign of ΔG° at 298 K? Explain.

(d) What is the sign of ΔH° at 298 K? Explain.

5. $$CaO(s) + CO_2(g) \rightarrow CaCO_3(s)$$

The reaction above is spontaneous at 298 K, and the heat of reaction, ΔH°, is -178 kJ.

(a) Predict the sign of the entropy change, ΔS°, for the reaction. Explain.

(b) What is the sign of ΔG° at 298 K? Explain.

(c) What change, if any, occurs to the value of ΔG° as the temperature is increased from 298 K?

(d) As the reaction takes place in a closed container, what changes will occur in the concentration of CO_2 and the temperature?

6. $$H_2O(l) \rightleftharpoons H_2O(g)$$

At 298 K, the value of the equilibrium constant, K, for the reaction above is 0.036.

(a) What is the sign of ΔS° for the reaction above at 298 K?

(b) What is the sign of ΔH° for the reaction above at 298 K?

(c) What is the sign of ΔG° for the reaction above at 298 K?

(d) At approximately what temperature will ΔG for the reaction be equal to zero?

12. If an endothermic reaction is spontaneous at 298 K, which of the following must be true for the reaction?

I. ΔG is greater than zero.
II. ΔH is greater than zero.
III. ΔS is greater than zero.

(A) I only
(B) II only
(C) I and II only
(D) II and III only
(E) I, II, and III

13. The addition of a catalyst will have which of the following effects on a chemical reaction?

I. The enthalpy change will decrease.
II. The entropy change will decrease.
III. The activation energy will decrease.

(A) I only
(B) II only
(C) III only
(D) I and II only
(E) II and III only

14. $C(s) + 2\,H_2(g) \rightarrow CH_4(g)$ $\quad \Delta H^\circ = x$

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\quad \Delta H^\circ = y$

$H_2(g) + \frac{1}{2}\,O_2(g) \rightarrow H_2O(l)$ $\quad \Delta H^\circ = z$

Based on the information given above, what is ΔH° for the following reaction?

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

(A) $x + y + z$
(B) $x + y - z$
(C) $z + y - 2x$
(D) $2z + y - x$
(E) $2z + y - 2x$

15. For which of the following processes will ΔS be positive?

I. $NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$
II. $2\,H_2(g) + O_2(g) \rightarrow 2\,H_2O(g)$
III. $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

(A) I only
(B) II only
(C) I and II only
(D) I and III only
(E) I, II, and III

16. In which of the following reactions is entropy increasing?

(A) $2\,SO_2(g) + O_2(g) \rightarrow 2\,SO_3(g)$
(B) $CO(g) + H_2O(g) \rightarrow H_2(g) + CO_2(g)$
(C) $H_2(g) + Cl_2(g) \rightarrow 2\,HCl(g)$
(D) $2\,NO_2(g) \rightarrow 2\,NO(g) + O_2(g)$
(E) $2\,H_2S(g) + 3\,O_2(g) \rightarrow 2\,H_2O(g) + 2\,SO_2(g)$

17. When pure sodium is placed in an atmosphere of chlorine gas, the following spontaneous reaction occurs.

$$2\,Na(s) + Cl_2(g) \rightarrow 2\,NaCl(s)$$

Which of the following statements is true about the reaction?

I. $\Delta S > 0$
II. $\Delta H < 0$
III. $\Delta G > 0$

(A) I only
(B) II only
(C) I and II only
(D) II and III only
(E) I, II, and III

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

Gaseous hydrogen and fluorine combine in the reaction above to form hydrogen fluoride with an enthalpy change of –540 kJ. What is the value of the heat of formation of HF(*g*)?

(A) –1,080 kJ/mol
(B) –540 kJ/mol
(C) –270 kJ/mol
(D) 270 kJ/mol
(E) 540 kJ/mol

19. $H_2O(s) \rightarrow H_2O(l)$

Which of the following is true of the reaction shown above at room temperature?

I. ΔG is greater than zero.
II. ΔH is greater than zero.
III. ΔS is greater than zero.

(A) II only
(B) III only
(C) I and II only
(D) I and III only
(E) II and III only

20. $2\,S(s) + 3\,O_2(g) \rightarrow 2\,SO_3(g)$
$\Delta H = +800$ kJ/mol

$2\,SO_3(g) \rightarrow 2\,SO_2(g) + O_2(g)$
$\Delta H = -200$ kJ/mol

Based on the information given above, what is ΔH for the following reaction?

$S(s) + O_2(g) \rightarrow SO_2(g)$

(A) 300 kJ
(B) 500 kJ
(C) 600 kJ
(D) 1,000 kJ
(E) 1,200 kJ

PROBLEMS

1.

Substance	Absolute Entropy, S° (J/mol-K)	Molecular Weight
$C_6H_{12}O_6$ (*s*)	212.13	180
O_2 (*g*)	205	32
CO_2 (*g*)	213.6	44
H_2O (*l*)	69.9	18

Energy is released when glucose is oxidized in the following reaction, which is a metabolism reaction that takes place in the body.

$$C_6H_{12}O_6(s) + 6\,O_2(g) \rightarrow 6\,CO_2(g) + 6\,H_2O(l)$$

The standard enthalpy change, $\Delta H°$, for the reaction is –2,801 kJ at 298 K.

(a) Calculate the standard entropy change, $\Delta S°$, for the oxidation of glucose.

(b) Calculate the standard free energy change, $\Delta G°$, for the reaction at 298 K.

(c) What is the value of K_{eq} for the reaction?

(d) How much energy is given off by the oxidation of 1.00 gram of glucose?

2.

Bond	Average Bond Dissociation Energy (kJ/mol)
C–H	415
O=O	495
C=O	799
O–H	463

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

The standard free energy change, $\Delta G°$, for the reaction above is –801 kJ at 298 K.

(a) Use the table of bond dissociation energies to find $\Delta H°$ for the reaction above.

(b) What is the value of K_{eq} for the reaction?

(c) What is the value of $\Delta S°$ for the reaction at 298 K?

(d) Give an explanation for the size of the entropy change found in (c).

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6 • Energy & Chemical Thermodynamics

PRACTICE TEST

$$C_2H_{2(g)} + 2\ H_{2(g)} \rightarrow C_2H_{6(g)}$$

Information about the substances involved in the reaction represented above is summarized in the following tables.

Substance	$\Delta H°f$ (kJ/mol)
$C_2H_{2(g)}$	226.7
$C_2H_{6(g)}$	-84.7

(a) Write the equation for the heat of formation of $C_2H_6(g)$

(b) Use the above information to determine the enthalpy of reaction for the equation given.

$$C_6H_5OH_{(s)} + 7\ O_{2(g)} \rightarrow 6\ CO_{2(g)} + 3\ H_2O_{(l)}$$

When a 2.000-gram sample of pure phenol, $C_6H_5OH_{(s)}$, is completely burned according to the equation above, 64.98 kilojoules of heat is released. Use the information in the table below to answer the questions that follow.

Substance	Standard Heat of Formation, $\Delta H°_f$; at 25°C (kJ/mol)
$CO_{2(g)}$	-393.5
$H_2O_{(l)}$	-285.85
$C_6H_5OH_{(s)}$	?

(a) Calculate the **molar** heat of combustion of phenol in kilojoules per mole at 25°C.

(b) Calculate the standard heat of formation, $\Delta H°_f$, of phenol in kilojoules per mole at 25°C.

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6 • Energy and Chemical Reactions

PRACTICE TEST

1. How many joules are equivalent to 37.7 cal?
   a) 9.01 J
   b) 4.184 J
   c) 1.51 J
   d) 158 J

2. The quantity of heat that is needed to raise the temperature of a sample of a substance 1.00 degree is called its
   a) heat capacity
   b) specific heat
   c) enthalpy
   d) kinetic energy

3. Equal masses of two substances, A & B, each absorb 25 Joules of energy. If the temperature of A increases by 4 degrees and the temperature of B increases by 8 degrees, one can say that
   a) the specific heat of A is double that of B.
   b) the specific heat of B is double that of A.
   c) the specific heat of B is negative.
   d) the specific heat of B is triple that of A.

4. If 25 J are required to change the temperature of 5.0 g of substance A by 2.0°C, what is the specific heat of substance A?
   a) 250 J/g°C
   b) 63 J/g°C
   c) 10. J/g°C
   d) 2.5 J/g°C

5. How much energy is required to change the temperature of 2.00 g aluminum from 20.0°C to 25.0°C? The specific heat of aluminum is 0.902 J/g°C.
   a) 2.3 J
   b) 9.0 J
   c) 0.36 J
   d) 0.090 J

6. Consider the thermal energy transfer during a chemical process. When heat is transferred to the system, the process is said to be _____ and the sign of ΔH is _____.
   a) exothermic, positive
   b) endothermic, negative
   c) exothermic, negative
   d) endothermic, positive

7. What is the ΔE for a system which has the following two steps:
   Step 1: The system absorbs 60 J of heat while 40 J of work are performed on it.
   Step 2: The system releases 30 J of heat while doing 70 J of work.
   a) 100 J
   b) 90 J
   c) 30 J
   d) zero

8. When two solutions react the container "feels hot." Thus,
   a) the reaction is endothermic.
   b) the reaction is exothermic.
   c) the energy of the universe is increased.
   d) the energy of both the system and the surroundings is decreased.

9. The equation for the standard enthalpy of formation of N_2O_3 is

a) $N_2O(g) + O_2(g) \rightarrow N_2O_3(g)$

b) $N_2O_5(g) \rightarrow N_2O_3(g) + O_2(g)$

c) $NO(g) + NO_2(g) \rightarrow N_2O_3(g)$

d) $N_2(g) + {}^3/_2\, O_2(g) \rightarrow N_2O_3(g)$

10. For the general reaction

$2\ A + B_2 \rightarrow 2\ AB$, ΔH is +50.0 kJ.

We can conclude that

a) the reaction is endothermic.

b) the surroundings absorb energy.

c) the standard enthalpy of formation of AB is -50.0 kJ.

d) the molecule AB contains less energy than A or B_2.

11. Calculate the enthalpy of combustion of C_3H_6:

$C_3H_6(g) + {}^9/_2O_2(g) \rightarrow 3CO_2 + 3H_2O$

using the following data:

$3C(s) + 3H_2(g) \rightarrow C_3H_6(g)$ $\Delta H° = 53.3$ kJ

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H° = -394$ kJ

$H_2(g) + {}^1/_2O_2(g) \rightarrow H_2O(l)$ $\Delta H° = -286$ kJ

a) -1517 kJ c) -626 kJ

b) 1304 kJ d) -2093 kJ

12. Which one of the following would have an enthalpy of formation value (ΔH_f) of zero?

a) $H_2O(g)$ c) $H_2O(l)$

b) $O(g)$ d) $O_2(g)$

13. Calculate the heat of vaporization of titanium (IV) chloride: $TiCl_4(l) \rightarrow TiCl_4(g)$

using the following enthalpies of reaction:

$Ti(s) + 2Cl_2(g) \rightarrow TiCl_4(l)$ $\Delta H° = -804.2$ kJ

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

a) -1567 kJ c) 1165 kJ

b) -783.7 kJ d) 41 kJ

14. Calculate the enthalpy of reaction for:

$D + F \rightarrow G + M$

using the following equations and data:

$G + C \rightarrow A + B$ $\Delta H° = +277$ kJ

$C + F \rightarrow A$ $\Delta H° = +303$ kJ

$D \rightarrow B + M$ $\Delta H° = -158$ kJ

a) -132 kJ c) +422 kJ

b) -422 kJ d) +132 kJ

15. Calculate the standard enthalpy of the reaction for the process

$3NO(g) \rightarrow N_2O(g) + NO_2(g)$

using the standard enthalpies of formation (in kJ/mol): NO = 90; N_2O = 82.1; NO_2 = 34.0

a) -153.9 kJ c) -26.1 kJ

b) 206 kJ d) 386 kJ

16. The standard molar enthalpy of combustion is -1277.3 kJ for the combustion of ethanol.

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

Calculate the standard molar enthalpy of formation for ethanol based on the following standard enthalpies of formation:

$\Delta H°_f\ CO_2 = -393.5$ kJ/mol

$\Delta H°_f\ H_2O = -241.8$ kJ/mol

a) -642.7 kJ/mol c) 235.1 kJ/mol

b) -235.1 kJ/mol d) 642.7 kJ/mol

17. Calculate the amount of heat needed to change 25.0 g ice at 0°C to water at 0°C. The heat of fusion of H_2O = 333 J/g;

a) 56.5 kJ c) 7.06 kJ

b) 8.33 kJ d) 463 kJ

Questions 18-20: (1/2 point each)

The following data was collected in an experiment similar to the Specific Heat experiment performed in class. Fill in the missing values. (Assume the calorimeter has a calorimeter constant of 0 J/°C)

	Data & Calculations	Glass Beads
	mass of glass beads	4.88 g
	mass of water	10.14 g
	initial temperature of water	19.2 °C
	initial temperature of beads	89.2 °C
	final temperature of mixture	24.8 °C
18.	temp change of water (°C)	
18.	temp change of hot beads (°C)	
19.	change in energy of water, q_{water} (J)	
	change in energy of calorimeter (J)	0 J
19.	change in energy of beads, q_{beads} (J)	
20.	specific heat of beads ($J \cdot g^{-1} \cdot °C^{-1}$)	
	accepted value of specific heat	.833
20.	% error	

Answers: (Please use CAPITAL letters) - **V1**

1.		11.	
2.		12.	
3.		13.	
4.		14.	
5.		15.	
6.		16.	
7.		17.	
8.			
9.		18.	
10.		18.	
		19.	
		19.	
		20.	
		20.	

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20 • Entropy and Free Energy

PRACTICE TEST

1. Which of the following represents an increase in entropy?
   a) freezing of water
   b) boiling of water
   c) crystallization of salt from a supersaturated solution
   d) the reaction $2\ NO(g) \rightarrow N_2O_2(g)$
   e) the reaction $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g)$

2. The enthalpy of vaporization of methanol (CH_3OH) is 35.3 kJ/mol at the boiling point of 64.2 °C. Calculate the entropy change for methanol going from a liquid to vapor.
   a) 600. J/K·mol
   b) 551 J/K·mol
   c) 105 J/K·mol
   d) -105 J/K·mol
   e) -551 J/K·mol

3. Calculate the standard entropy change for the following reaction,

   $Cu(s) + \frac{1}{2}\ O_2(g) \rightarrow CuO(s)$

   given that

$S°[Cu(s)] = 33.15$ J/K·mol
$S°[O_2(g)] = 205.14$ J/K·mol
$S°[CuO(s)] = 42.63$ J/K·mol

   a) 195.66 J/K
   b) 93.09 J/K
   c) -45.28 J/K
   d) -93.09 J/K
   e) 195.66 J/K

4. In which of the following reactions do you expect to have a decrease in entropy?
   a) $Fe(s) \rightarrow Fe(l)$
   b) $Fe(s) + S(s) \rightarrow FeS(s)$
   c) $2\ Fe(s) + 3/2\ O_2(g) \rightarrow Fe_2O_3(s)$
   d) $HF(l) \rightarrow HF(g)$
   e) $2\ H_2O_2(l) \rightarrow 2\ H_2O(l) + O_2(g)$

5. The formation $\frac{1}{2}\ A_2 + 2\ B_2 + C \rightarrow CAB_4$ has an enthalpy of formation of -104 kJ and a change in entropy of -60.8 J/K at 30 °C. What is ΔG and spontaneity of the reaction?
   a) -85.6 kJ, spontaneous
   b) -18.3 kJ, not spontaneous
   c) +18.3 kJ, spontaneous
   d) +85.6 kJ, not spontaneous
   e) -85.6 kJ, not spontaneous

6. If ΔH and ΔS are both negative or positive, then ΔG has a _____ sign.
   a) positive
   b) negative
   c) variable
   d) large
   e) no

7. At what temperature would a given reaction become spontaneous if $\Delta H = +119$ kJ and $\Delta S = +263$ J/K? (assume $G = 0$)
   a) 452 K
   b) 2210 K
   c) 382 K
   d) 2.21 K
   e) 363 K

8. The free energy change for a given reaction is -36.2 kJ. What is the equilibrium constant at 298 K?
   a) 0.985
   b) 2.22×10^6
   c) 1.01
   d) 8.32×10^{-7}
   e) 3.25×10^6

9. Given the following information, calculate $\Delta G°$ for the reaction below at 25°C:

   $SnCl_4(l) + 2\ H_2O(l) \rightarrow SnO_2(s) + 4\ HCl(g)$

   $\Delta H° = 133.0$ kJ and $\Delta S° = 401.5$ J/K
   a) -252.6 kJ
   b) -13.4 kJ
   c) 13.4 kJ
   d) 122.9 kJ
   e) 252.6 kJ

10. Given the following information, calculate $\Delta G°$ for the reaction below at 25°C:

$$2\ H_2O_2(l) \rightarrow 2\ H_2O(l) + O_2(g)$$

Compound	$\Delta H°$(kJ/mol)	$S°$(J/K·mol)
$H_2O_2(l)$	-187.8	109.6
$H_2O(l)$	-285.8	69.9
$O_2(g)$	——	205.1

a) -37700 kJ
b) -342.6 kJ
c) -233.5 kJ
d) 233.5 kJ
e) -157.9 kJ

11. For the process at 25°C

$$I_2(g) \rightarrow I_2(s)$$

what are the signs of ΔG, ΔH, and ΔS?

	ΔG	ΔH	ΔS
a)	+	–	–
b)	–	–	–
c)	–	+	+
d)	–	–	+
e)	+	+	+

12. If a process is exothermic and not spontaneous, then what must be true?

a) $\Delta S > 0$
b) $\Delta H > 0$
c) $\Delta G = 0$
d) $\Delta S < 0$
e) $\Delta H = 0$

13. For any reaction at equilibrium, which of the following is true?

a) $\Delta H < 0$
b) $\Delta S = 0$
c) $\Delta S < 0$
d) $\Delta H = 0$
e) $\Delta G = 0$

14. All of the following have $\Delta G°_f = 0$ EXCEPT

a) $O_2(g)$
b) $Br_2(g)$
c) $H_2(g)$
d) Ca(s)
e) Hg(l)

15. Ammonium nitrate spontaneously dissolves in water at room temperature and the process causes the solution to become quite cold. Which of the following is TRUE about the dissolution of ammonium nitrate?

a) The process is exothermic.
b) Its solubility will be greater in warmer water.
c) $\Delta S°$ for the reaction is negative.
d) All solutions of ammonium nitrate are supersaturated.
e) All solutions of ammonium nitrate are cold.

Answers:

1.		6.		11.	
2.		7.		12.	
3.		8.		13.	
4.		9.		14.	
5.		10.		15.	

From the AP Exam formula sheet:

THERMOCHEMISTRY

$$\Delta S° = \sum S° \text{ products} - \sum S° \text{ reactants}$$

$$\Delta H° = \sum \Delta H_f° \text{ products} - \sum \Delta H_f° \text{ reactants}$$

$$\Delta G° = \sum \Delta G_f° \text{ products} - \sum \Delta G_f° \text{ reactants}$$

$$\Delta G° = \Delta H° - T\Delta S°$$

$$= -RT \ln K = -2.303\ RT \log K$$

$$= -n\mathcal{F}E°$$

$$\Delta G = \Delta G° + RT \ln Q = \Delta G° + 2.303\ RT \log Q$$

$$q = mc\Delta T$$

$$C_p = \frac{\Delta H}{\Delta T}$$

NChO 1999

25. Under which set of conditions is a chemical reaction most likely to be spontaneous?

	ΔH	ΔS	T (temperature)
(A)	–	–	low
(B)	–	–	high
(C)	+	+	low
(D)	+	–	high

26. For which reaction do you expect ΔS to be negative?

(A) $2C(s) + O_2(g) \rightarrow 2CO(g)$

(B) $Br_2(s) \rightarrow Br_2(l)$

(C) $H_2O(l, 25\ °C) \rightarrow H_2O(l, 50\ °C)$

(D) $Cl_2(g) + 2HI(g) \rightarrow I_2(s) + 2HCl(g)$

NChO 1998

23. Which has the greatest absolute entropy?

(A) one mol of C(s) at 25 °C

(B) one mol of $CH_3Cl(l)$ at 25 °C

(C) one mol of $C_2H_6(g)$ at 25 °C

(D) one mol of $C_6H_6(l)$ at 25 °C

NChO 1997

26. For which of these processes would ΔS° be expected to be the most positive?

(A) $O_2(g) + 2H_2(g) \rightarrow 2H_2O(g)$

(B) $H_2O(l) \rightarrow H_2O(s)$

(C) $N_2O_4(g) \rightarrow 2NO_2(g)$

(D) $NH_4NO_2(s) \rightarrow N_2(g) + 2H_2O(g)$

NChO 1996

24. For which of these processes is the value of ΔS expected to be negative?

I. Sugar is dissolved in water

II. Steam is condensed

III. $CaCO_3$ is decomposed into CaO and CO_2.

(A) I only (C) II only

(B) I and III only (D) II and III only

25. Which set of conditions is most likely to result in a reaction that is spontaneous as written?

	ΔH	ΔS	T
(A)	< 0	< 0	500 °C
(B)	< 0	< 0	0 °C
(C)	> 0	< 0	0 °C
(D)	> 0	< 0	500 °C

NChO 1995

21. For which of these processes is the sign of the enthalpy change different from the others?

(A) $Al_2O_3(s) \rightarrow 2\ Al(s) + 3/2\ O_2(g)$

(B) $H_2O(s) \rightarrow H_2O(l)$

(C) $Cl_2(g) \rightarrow 2Cl(g)$

(D) $Cl(g) + e^- \rightarrow Cl^-(g)$

24. For the process $O_2(g) \rightarrow 2\ O(g)$, $\Delta H° = +498$ kJ. What would be predicted for the sign of ΔS_{rxn} and the conditions under which this reaction would be spontaneous?

	ΔS_{rxn}	Spontaneous
(A)	positive	at low temperatures only
(B)	positive	at high temperatures only
(C)	negative	at high temperatures only
(D)	negative	at low temperatures only

25. For the reaction

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

$\Delta H° = +176$kJ and $\Delta G° = +91.2$ kJ at 298 K. What is the value of ΔG at 1000 K?

(A) -109 kJ (C) +64 kJ

(B) -64 kJ (D) +109 kJ

NChO 1994

23. When ammonium nitrate, $NH_4NO_3(s)$ is added to water at 25 °C, it dissolves spontaneously and the temperature of the solution decreases. This indicates that the factor causing the substance to dissolve is a change in

(A) energy (C) entropy

(B) enthalpy (D) temperature

Name:_____ Date:_____

Advanced Chemistry Chapter 6 Review

This is a general review for some of the topics that we covered in chapter 6. This is intended as a supplementary study tool, all material in notes and in the text may be tested on. (3 pts each, 45 pts total)

1. If I burn 0.315 moles of hexane (C_6H_{14}) in a bomb calorimeter containing 5.65 liters of water, what's the molar heat of combustion of hexane is the water temperature rises 55.4^0 C? The heat capacity of water is 4.184 J/g^{0}C

2. If I burn 22.0 grams of propane (C_3H_8) in a bomb calorimeter containing 3.25 liters of water, what's the molar heat of combustion of propane if the water temperature rises 29.5^0 C?

3. The_____ is the energy needed to raise the temperature of a substance by one degree Celsius.

4. A(n) _____reaction is one where the products have lower energy than the reactants.

5. _____reactions require energy in order to take place.

6. The _____is used to describe how much energy is produced or used during a chemical change.

7. What is a state function, give one example and one non-example with explanations:

8. What are the equations for heat capacity and specific heat (identify all variables).

9. What is the definition of heat capacity and it units?

10. What is the definition of specific heat and its units?

11. A 23.1 g sample of ethanol was warmed from 25.00 to 27.34 °C by absorbing 132 J of heat. What is the specific heat of ethanol?

12. Define the ΔH for the reaction $NO + O \rightarrow NO_2$

a) $NO + O_3 \rightarrow NO_2 + O_2$ $\Delta H = -198.9$ kJ

b) $O_3 \rightarrow 3/2\ O_2$ $\Delta H = -142.3$ kJ

c) $O_2 \rightarrow 2O$ $\Delta H = 495.0$ kJ

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13. How much heat would be released when 10.0 g of hydrogen are burned according to the following reaction:

$$2H_2\,(g) + O_2\,(g) \rightarrow 2H_2O\,(l) \qquad \Delta H = -484\ kJ$$

14. Find the standard enthalpy change ($\Delta H°_{rxn}$) for the reaction below. Use the tabulated standard enthalpies of formation values in the appendix of your text (I will always give you these)

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

15. Write an equation that represents the standard heat of formation ($\Delta H°_f$) of $CH_3OH\,(l)$

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