19.1 Multiple-Choice and Bimodal Questions

Use the table below to answer the questions that follow.

Thermodynamic Quantities for Selected Substances at 298.15 K (25°C)

Substance	ΔH°f (kJ/mol)	ΔG°f (kJ/mol)	S (J/K-mol)
Carbon			
C (s, diamond)	1.88	2.84	2.43
C (s, graphite)	0	0	5.69
C_2H_2 (g)	226.7	209.2	200.8
C_2H_4 (g)	52.30	68.11	219.4
C_2H_6 (g)	-84.68	-32.89	229.5
CO (g)	-110.5	-137.2	197.9
CO_2 (g)	-393.5	-394.4	213.6
Hydrogen			
H_2(g)	0	0	130.58
Oxygen			
O_2 (g)	0	0	205.0
H_2O (l)	-285.83	-237.13	69.91

1) The value of $\Delta S°$ for the catalytic hydrogenation of acetylene to ethene,

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

is _____ J/K· mol.

A) +18.6
B) +550.8
C) +112.0
D) -112.0
E) -18.6

2) The combustion of acetylene in the presence of excess oxygen yields carbon dioxide and water:

$$2C_2H_2(g) + 5O_2 \rightarrow 4CO_2(g) + 2H_2O(l)$$

The value of $\Delta S°$ for this reaction is _____ J/K· mol.

A) +689.3
B) +122.3
C) +432.4
D) -122.3
E) -432.4

3) The value of $\Delta S°$ for the reaction

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

is _____ J/K· mol.

A) -185.9
B) +185.9
C) -9.5
D) +9.5
E) -195.7

4) The value of $\Delta S°$ for the catalytic hydrogenation of ethene to ethane,

$$C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$$

is _____ J/K· mol.

A) -101.9
B) -120.5
C) -232.5
D) +112.0
E) +101.9

5) The value of $\Delta S°$ for the catalytic hydrogenation of acetylene to ethane

$$C_2H_2(g) + 2H_2(g) \rightarrow C_2H_6(g)$$

is _____ J/K· mol.

A) -76.0
B) +440.9
C) -232.5
D) +232.5
E) +28.7

6) The value of $\Delta S°$ for the oxidation of carbon to carbon monoxide,

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

is _____ J/K· mol. Carbon monoxide is produced in the combustion of carbon with limited oxygen.

A) -12.8
B) +408.6
C) -408.6
D) +179.4
E) +395.8

7) The value of $\Delta S°$ for the oxidation of carbon to

carbon dioxide,

$$C(s,\text{graphite}) + O_2(g) \rightarrow CO_2(g)$$

is _____ J/K· mol. The combustion of carbon, as in charcoal briquettes, in the presence of abundant oxygen produces carbon dioxide.

A) +424.3
B) +205.0
C) -205.0
D) -2.9
E) +2.9

8) The combustion of ethene in the presence of excess oxygen yields carbon dioxide and water:

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

The value of ΔS° for this reaction is _____ J/K· mol.

A) -267.4
B) -140.9
C) -347.6
D) +347.6
E) +140.9

9) The combustion of ethane in the presence of excess oxygen yields carbon dioxide and water:

$$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(l)$$

The value of $\Delta S°$ for this reaction is _____ J/K· mol.

A) +718.0
B) -620.1
C) -718.0
D) -151.0
E) +151.0

10) The combustion of hydrogen in the presence of excess oxygen yields water:

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

The value of $\Delta S°$ for this reaction is _____ J/K· mol.

A) +405.5
B) -405.5
C) -326.3
D) -265.7
E) +265.7

Use the table below to answer the questions that follow.

Thermodynamic Quantities for Selected Substances at 298.15 K (25°C)

Substance	$\Delta H°_f$ (kJ/mol)	$\Delta G°_f$ (kJ/mol)	S (J/K-mol)
Calcium			
Ca (s)	0	0	41.4
$CaCl_2$ (s)	-795.8	-748.1	104.6
Ca_2^+ (aq)	226.7	209.2	200.8
Chlorine			
Cl_2 (g)	0	0	222.96
Cl- (aq)	-167.2	-131.2	56.5
Oxygen			
O_2 (g)	0	0	205.0
H_2O (l)	-285.83	-237.13	69.91
Phosphorus			
P_2 (g)	144.3	103.7	218.1
PCl_3 (g)	-288.1	-269.6	311.7
$POCl_3$ (g)	-542.2	-502.5	325
Sulfur			
S (s, rhombic)	0	0	31.88
SO_2(g)	-269.9	-300.4	248.5
SO_3(g)	-395.2	-370.4	256.2

11) The value of $\Delta S°$ for the oxidation of solid elemental sulfur to gaseous sulfur trioxide,

$$2S(s,\text{rhombic}) + 3O_2(g) \rightarrow 2SO_3(g)$$

is _____ J/K· mol.

A) +19.3
B) -19.3
C) +493.1
D) -166.4
E) -493.1

12) The value of $\Delta S°$ for the oxidation of solid elemental sulfur to gaseous sulfur dioxide,

$$S(s,\text{rhombic}) + O_2(g) \rightarrow SO_2(g)$$

is _____ J/K· mol.

A) +485.4
B) +248.5
C) -11.6

D) -248.5
E) +11.6

13) The value of $\Delta S°$ for the decomposition of gaseous sulfur trioxide to solid elemental sulfur and gaseous oxygen,

$$2SO_3(g) \rightarrow 2S(s, \text{rhombic}) + 3O_2(g)$$

is _____ J/K· mol.

A) +19.3
B) -19.3
C) +493.1
D) +166.4
E) -493.1

14) The value of $\Delta S°$ for the decomposition of gaseous sulfur dioxide to solid elemental sulfur and gaseous oxygen,

$$SO_2(g) \rightarrow S(s, \text{rhombic}) + O_2(g)$$

is _____ J/K· mol.

A) +485.4
B) +248.5
C) -11.6
D) -248.5
E) +11.6

15) The value of $\Delta S°$ for the formation of $POCl_3$ from its constituent elements,

$$P_2(g) + O_2(g) + 3Cl_2(g) \rightarrow 2POCl_3(g)$$

is _____ J/K· mol.

A) -442.0
B) +771.0
C) -321.0
D) -771.0
E) +321.0

16) The value of $\Delta S°$ for the decomposition of $POCl_3$ into its constituent elements,

$$2POCl_3(g) \rightarrow P_2(g) + O_2(g) + 3Cl_2(g)$$

is _____ J/K· mol.

A) +771.0
B) +442.0
C) -321.0
D) -771.0
E) +321.0

17) The value of $\Delta S°$ for the formation of phosphorous trichloride from its constituent elements,

$$P_2(g) + 3Cl_2(g) \rightarrow 2PCl_3(g)$$

is _____ J/K· mol.

A) -311.7
B) +311.7
C) -263.6
D) +129.4
E) -129.4

18) The value of $\Delta S°$ for the decomposition of phosphorous trichloride into its constituent elements,

$$2PCl_3(g) \rightarrow P_2(g) + 3Cl_2(g)$$

is _____ J/K· mol.

A) -311.7
B) +311.7
C) +263.6
D) +129.4
E) -129.4

19) The value of $\Delta S°$ for the formation of calcium chloride from its constituent elements,

$$Ca(s) + Cl_2(g) \rightarrow CaCl_2(s)$$

is _____ J/K· mol.

A) -104.6
B) +104.6
C) +369.0
D) -159.8
E) +159.8

20) The value of $\Delta S°$ for the decomposition of calcium chloride into its constituent elements,

$$CaCl_2(s) \rightarrow Ca(s) + Cl_2(g)$$

is _____ J/K· mol.

A) -104.6
B) +104.6

C) +369.0
D) -159.8
E) +159.8

21) The value of $\Delta H°$ for the oxidation of solid elemental sulfur to gaseous sulfur trioxide,

$$2S(s,\text{rhombic}) + 3O_2(g) \rightarrow 2SO_3(g)$$

is _____ kJ/mol.

A) +790.4
B) -790.4
C) +395.2
D) -395.2
E) +105.1

22) The value of $\Delta H°$ for the decomposition of gaseous sulfur trioxide to its component elements,

$$2SO_3(g) \rightarrow 2S(s,\text{rhombic}) + 3O_2(g)$$

is _____ kJ/mol.

A) +790.4
B) -790.4
C) +395.2
D) -395.2
E) +105.1

23) The value of $\Delta H°$ for the oxidation of solid elemental sulfur to gaseous sulfur dioxide,

$$S(s,\text{rhombic}) + O_2(g) \rightarrow SO_2(g)$$

is _____ kJ/mol.

A) +269.9
B) -269.9
C) +0.00
D) -11.6
E) +11.6

24) The value of $\Delta H°$ for the decomposition of gaseous sulfur dioxide to solid elemental sulfur and gaseous oxygen,

$$SO_2(g) \rightarrow S(s,\text{rhombic}) + O_2(g)$$

is _____ kJ/mol.

A) +0.0
B) +135.0
C) -135.90
D) -269.9
E) +269.9

25) The value of $\Delta H°$ for the formation of $POCl_3$ from its constituent elements,

$$P_2(g) + O_2(g) + 3Cl_2(g) \rightarrow 2POCl_3(g)$$

is _____ kJ/mol.

A) -1228.7
B) -397.7
C) -686.5
D) +1228.7
E) +686.5

26) The value of $\Delta H°$ for the decomposition of $POCl_3$ into its constituent elements,

$$2POCl_3(g) \rightarrow P_2(g) + O_2(g) + 3Cl_2(g)$$

is _____ kJ/mol.

A) -1,228.7
B) +1,228.7
C) -940.1
D) +940.1
E) +0.00

27) The value of $\Delta H°$ for the formation of phosphorous trichloride from its constituent elements,

$$P_2(g) + 3Cl_2(g) \rightarrow 2PCl_3(g)$$

is _____ kJ/mol

A) -288.1
B) +432.4
C) -720.5
D) +720.5
E) -432.4

28) The value of $\Delta H°$ for the decomposition of phosphorous trichloride into its constituent elements,

$$2PCl_3(g) \rightarrow P_2(g) + 3Cl_2(g)$$

is _____ kJ/mol.

A) +576.2
B) -288.1

C) +720.5
D) +288.1
E) -720.5

29) The value of $\Delta H°$ for the formation of calcium chloride from its constituent elements,

$$Ca(s) + Cl_2(g) \rightarrow CaCl_2(s)$$

is _____ kJ/mol.

A) +0.00
B) -397.9
C) +397.9
D) -795.8
E) +795.8

30) The value of $\Delta H°$ for the decomposition of calcium chloride into its constituent elements,

$$CaCl_2(s) \rightarrow Ca(s) + Cl_2(g)$$

is _____ kJ/mol.

A) -0.00
B) -397.9
C) +397.9
D) -795.8
E) +795.8

31) The value of $\Delta G°$ at 25 °C for the oxidation of solid elemental sulfur to gaseous sulfur trioxide,

$$2S(s,rhombic) + 3O_2(g) \rightarrow 2SO_3(g)$$

is _____ kJ/mol.

A) +740.8
B) -370.4
C) +370.4
D) -740.8
E) +185.2

32) The value of $\Delta G°$ at 25 °C for the oxidation of solid elemental sulfur to gaseous sulfur dioxide,

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

is _____ kJ/mol.

A) +395.2
B) +269.9
C) -269.9
D) +300.4
E) -300.4

33) The value of $\Delta G°$ at 25 °C for the decomposition of gaseous sulfur trioxide to solid elemental sulfur and gaseous oxygen,

$$2SO_3(g) \rightarrow 2S(s,rhombic) + 3O_2(g)$$

is _____ kJ/mol.

A) +740.8
B) -370.4
C) +370.4
D) -740.8
E) +185.2

34) The value of $\Delta G°$ at 25 °C for the decomposition of gaseous sulfur dioxide to solid elemental sulfur and gaseous oxygen,

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

is _____ kJ/mol.

A) +395.2
B) +269.9
C) -269.9
D) +300.4
E) -300.4

35) The value of $\Delta G°$ at 25 °C for the formation of $POCl_3$ from its constituent elements,

$$P_2(g) + O_2(g) + 3Cl_2(g) \rightarrow 2POCl_3(g)$$

is _____ kJ/mol.

A) -1,108.7
B) +1,108.7
C) -606.2
D) +606.2
E) -1,005

36) The value of $\Delta G°$ at 25 °C for the decomposition of $POCl_3$ into its constituent elements,

$$2POCl_3(g) \rightarrow P_2(g) + O_2(g) + 3Cl_2(g)$$

is _____ kJ/mol.

A) -1,108.7

B) +1,108.7
C) -606.2
D) +606.2
E) -1,005

37) The value of $\Delta G°$ at 25 °C for the formation of phosphorous trichloride from its constituent elements,

$$P_2(g) + 3Cl_2(g) \rightarrow 2PCl_3(g)$$

is _____ kJ/mol.

A) -539.2
B) +539.2
C) -642.9
D) +642.9
E) -373.3

38) The value of $\Delta G°$ at 25 °C for the decomposition of phosphorous trichloride into its constituent elements,

$$2PCl_3(g) \rightarrow P_2(g) + 3Cl_2(g)$$

is _____ kJ/mol.

A) -539.2
B) +539.2
C) -642.9
D) +642.9
E) -373.3

39) The value of $\Delta G°$ at 25 °C for the formation of calcium chloride from its constituent elements,

$$Ca(s) + Cl_2(g) \rightarrow CaCl_2(s)$$

is _____ kJ/mol.

A) -795.8
B) +795.8
C) +763.7
D) +748.1
E) -748.1

40) The value of $\Delta G°$ at 25 °C for the decomposition of calcium chloride into its constituent elements,

$$CaCl_2(s) \rightarrow Ca(s) + Cl_2(g)$$

is _____ kJ/mol.

A) -795.8
B) +795.8
C) +763.7
D) +748.1
E) -748.1

41) The value of $\Delta G°$ at 373 K for the oxidation of solid elemental sulfur to gaseous sulfur dioxide,

$$S(s,\text{rhombic}) + O_2(g) \rightarrow SO_2(g)$$

is _____ kJ/mol. At 298 K, $\Delta H°$ for this reaction is -269.9 kJ/mol, and $\Delta S°$ is +11.6 J/K.

A) -300.4
B) +300.4
C) -4,597
D) +4,597
E) -274.2

42) Given the thermodynamic data in the table below, calculate the equilibrium constant (at 298 K) for the reaction:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

Substance	$\Delta H_f°$ (kJ/mol)	$S°$ (J/mol · K)
SO_2 (g)	-297	249
O_2 (g)	0	205
SO_3 (g)	-395	256

A) 2.37×10^{24}
B) 1.06
C) 1.95
D) 3.82×10^{23}
E) More data are needed.

43) The equilibrium constant for a reaction is 0.48 at 25 °C. What is the value of $\Delta G°$ (kJ/mol) at this temperature?

A) 1.8
B) -4.2
C) 1.5×10^2
D) 4.2
E) More information is needed.

44) The equilibrium constant for the following

reaction is 5.0×10^{8} at 25 °C.

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

The value of $\Delta G°$ for this reaction is _____ kJ/mol.

A) 22
B) -4.2
C) -25
D) -50
E) -22

45) Consider the reaction:

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

Given the following table of thermodynamic data at 298 K:

Substance	$\Delta H_f°$ (kJ/mol)	$S°$ (J/K • mol)
NH_3 (g)	-46.19	192.5
HCl (g)	-92.30	186.69
NH_4Cl (s)	-314.4	94.6

The value of K for the reaction at 25 °C is _____.

A) 150
B) 9.2×10^{15}
C) 8.4×10^{4}
D) 1.1×10^{-16}
E) 1.4×10^{8}

46) Consider the reaction:

$$FeO(s) + Fe(s) + O_2(g) \rightarrow Fe_2O_3(s)$$

Given the following table of thermodynamic data at 298 K:

Substance	$\Delta H_f°$ (kJ/mol)	$S°$ (J/K • mol)
FeO (s)	-271.9	60.75
Fe (s)	0	27.15
O_2 (g)	0	205.0
Fe_2O_3 (s)	-822.16	89.96

The value K for the reaction at 25 °C is _____.

A) 370
B) 5.9×10^{4}
C) 3.8×10^{-14}
D) 7.1×10^{85}
E) 8.1×10^{19}

47) Consider the reaction:

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$

Given the following table of thermodynamic data at 298 K:

Substance	$\Delta H_f°$ (kJ/mol)	$S°$ (J/K • mol)
Ag^+ (aq)	105.90	73.93
Cl^- (aq)	-167.2	56.5
AgCl(s)	-127.0	96.11

The value of K for the reaction at 25 °C is _____.

A) 810
B) 5.3×10^{9}
C) 1.8×10^{4}
D) 3.7×10^{10}
E) 1.9×10^{-10}

19.2 Multiple-Choice Questions:

1) The first law of thermodynamics can be given as _____.

A) $\Delta E = q + w$
B) $\Delta H°_{rxn} = \sum n\Delta H°_f(\text{products}) - \sum m\Delta H°_f(\text{reactants})$
C) for any spontaneous process, the entropy of the universe increases
D) the entropy of a pure crystalline substance at absolute zero is zero
E) $\Delta S = q_{rev}/T$ at constant temperature

2) A reaction that is spontaneous as written _____.

A) is very rapid
B) will proceed without outside intervention
C) is also spontaneous in the reverse direction
D) has an equilibrium position that lies far to the left
E) is very slow

3) Of the following, only _____ is <u>not</u> a state function.

A) S
B) H
C) q
D) E
E) T

4) When a system is at equilibrium, _____.

A) the reverse process is spontaneous but the forward process is not
B) the forward and the reverse processes are both spontaneous
C) the forward process is spontaneous but the reverse process is not
D) the process is not spontaneous in either direction
E) both forward and reverse processes have stopped

5) A reversible process is one that _____.

A) can be reversed with no net change in either system or surroundings
B) happens spontaneously
C) is spontaneous in both directions
D) must be carried out at low temperature
E) must be carried out at high temperature

6) Which of the following statements is true?

A) Processes that are spontaneous in one direction are spontaneous in the opposite direction.
B) Processes are spontaneous because they occur at an observable rate.
C) Spontaneity can depend on the temperature.
D) All of the statements are true.

7) The thermodynamic quantity that expresses the degree of disorder in a system is _____.

A) enthalpy
B) internal energy
C) bond energy
D) entropy
E) heat flow

8) For an isothermal process, ΔS = _____.

A) q
B) q_{rev}/T
C) q_{rev}
D) Tq_{rev}
E) $q + w$

9) Which one of the following is always positive when a spontaneous process occurs?

A) ΔS_{system}
B) $\Delta S_{surroundings}$
C) $\Delta S_{universe}$
D) $\Delta H_{universe}$
E) $\Delta H_{surroundings}$

10) The entropy of the universe is _____.

A) constant
B) continually decreasing
C) continually increasing
D) zero
E) the same as the energy, E

11) The second law of thermodynamics states that _____.

A) $\Delta E = q + w$
B) $\Delta H°_{rxn} = \Sigma\, n\Delta H°_f$ (products) - $\Sigma\, m\Delta H°_f$ (reactants)
C) for any spontaneous process, the entropy of the universe increases
D) the entropy of a pure crystalline substance is zero at absolute zero
E) $\Delta S = q_{rev}/T$ at constant temperature

12) The normal boiling point of water is 100.0 °C and its molar enthalpy of vaporization is 40.67 kJ/mol. What is the change in entropy in the system in J/K when 39.3 grams of steam at 1 atm condenses to a liquid at the normal boiling point?

A) 88.8
B) -88.8
C) -238
D) 373

E) -40.7

13) The normal boiling point of $C_2Cl_3F_3$ is 47.6 °C and its molar enthalpy of vaporization is 27.49 kJ/mol. What is the change in entropy in the system in J/K when 28.6 grams of $C_2Cl_3F_3$ vaporizes to a gas at the normal boiling point?

A) -13.1
B) -4.19
C) 4.19
D) 13.1
E) 27.5

14) The normal boiling point of ethanol (C_2H_5OH) is 78.3 °C and its molar enthalpy of vaporization is 38.56 kJ/mol. What is the change in entropy in the system in J/K when 97.2 grams of ethanol at 1 atm condenses to a liquid at the normal boiling point?

A) -81.4
B) -4.5
C) 38.6
D) 81.4
E) -231

15) Which of the following statements is false?

A) The change in entropy in a system depends on the initial and final states of the system and the path taken from one state to the other.
B) Any irreversible process results in an overall increase in entropy.
C) The total entropy of the universe increases in any spontaneous process.
D) Entropy increases with the number of microstates of the system.

16) ΔS is positive for the reaction _____.

A) $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$
B) $2NO_2(g) \rightarrow N_2O_4(g)$
C) $CO_2(g) \rightarrow CO_2(s)$
D) $BaF_2(s) \rightarrow Ba^{2+}(aq) + 2F^-(aq)$
E) $2Hg(l) + O_2(g) \rightarrow 2HgO(s)$

17) Which one of the following processes produces a decrease in the entropy of the system?

A) boiling water to form steam
B) dissolution of solid KCl in water
C) mixing of two gases into one container
D) freezing water to form ice
E) melting ice to form water

18) ΔS is positive for the reaction _____.

A) $CaO(s) + CO_2(g) \rightarrow CaCO_3(s)$
B) $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$
C) $2SO_3(g) \rightarrow 2SO_2(g) + O_2(g)$
D) $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$
E) $H_2O(l) \rightarrow H_2O(s)$

19) Which reaction produces a decrease in the entropy of the system?

A) $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$
B) $2C(s) + O_2(g) \rightarrow 2CO(g)$
C) $CO_2(s) \rightarrow CO_2(g)$
D) $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$
E) $H_2O(l) \rightarrow H_2O(g)$

20) Which reaction produces an increase in the entropy of the system?

A) $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$
B) $CO_2(s) \rightarrow CO_2(g)$
C) $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$
D) $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$
E) $H_2O(l) \rightarrow H_2O(s)$

21) Which one of the following processes produces a decrease of the entropy of the system?

A) dissolving sodium chloride in water
B) sublimation of naphthalene

C) dissolving oxygen in water
D) boiling of alcohol
E) explosion of nitroglycerine

22) ΔS is negative for the reaction _____.

A) $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$
B) $NH_4Cl(s) \rightarrow NH_3(g) + HCl(g)$
C) $PbCl_2(s) \rightarrow Pb^{2+}(aq) + 2Cl^-(aq)$
D) $2C(s) + O_2(g) \rightarrow 2CO_2(g)$
E) $H_2O(l) \rightarrow H_2O(g)$

23) ΔS is positive for the reaction _____.

A) $Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$
B) $2H_2O(g) \rightarrow 2H_2(g) + O_2(g)$
C) $H_2O(g) \rightarrow H_2O(s)$
D) $NO(g) + O_2(g) \rightarrow NO_2(g)$
E) $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

24) ΔS is negative for the reaction _____.

A) $2H_2O(g) \rightarrow 2H_2(g) + O_2(g)$
B) $Mg(NO_3)_{2\,(aq)} + 2NaOH_{(aq)} \rightarrow Mg(OH)_{2\,(s)} + 2NaNO_{3\,(aq)}$
C) $H_2O(l) \rightarrow H_2O(g)$
D) $C_6H_{12}O_6(s) \rightarrow 6C(s) + 6H_2(g) + 3O_2(g)$
E) $NaCl(aq) \rightarrow Na^+(aq) + Cl^-(aq)$

25) Consider a pure crystalline solid that is heated from absolute zero to a temperature above the boiling point of the liquid. Which of the following processes produces the greatest increase in the entropy of the substance?

A) melting the solid
B) heating the liquid
C) heating the gas
D) heating the solid
E) vaporizing the liquid

26) Which one of the following correctly indicates the relationship between the entropy of a system and the number of different arrangements, W, in the system?

A) S = kW
B) $S = \frac{k}{W}$
C) $S = \frac{W}{k}$
D) $S = k \ \ln W$
E) S = Wk

27) The entropy change accompanying any process is given by the equation:

A) $\Delta S = k \ln W_{final}$
B) $\Delta S = k\ W_{final} - k\ W_{initial}$
C) $\Delta S = k \ln(W_{final} / W_{initial})$
D) $\Delta S = k_{\ final} - k_{\ initial}$
E) $\Delta S = W_{final} - W_{initial}$

28) Of the following, the entropy of _____ is the largest.

A) HCl (l)
B) HCl (s)
C) HCl (g)
D) HBr (g)
E) HI (g)

29) Of the following, the entropy of gaseous _____ is the largest at 25 °C and 1 atm.

A) H_2
B) C_2H_6
C) C_2H_2
D) CH_4
E) C_2H_4

30) For an isothermal process, the entropy change of the surroundings is given by the equation:

A) $\Delta S = q_{sys}\ T$

B) $\Delta S = -q_{sys}\, T$
C) $\Delta S = q \ln T$
D) $\Delta S = -q \ln T$
E) $\Delta S = -q_{sys} / T$

31) The standard Gibbs free energy of formation of _____ is zero.
(a) $H_2O(l)$
(b) $O(g)$
(c) $H_2(g)$

A) (a) only
B) (b) only
C) (c) only
D) (b) and (c)
E) (a), (b), and (c)

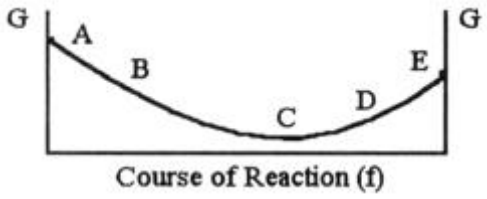
32) The standard Gibbs free energy of formation of _____ is zero.
(a) $H_2O(l)$
(b) Na(s)
(c) $H_2(g)$

A) (a) only
B) (b) only
C) (c) only
D) (b) and (c)
E) (a), (b), and (c)

33) The standard Gibbs free energy of formation of _____ is zero.
(a) Al (s)
(b) Br_2 (l)
(c) Hg (l)

A) (a) only
B) (b) only
C) (c) only
D) (b) and (c)
E) (a), (b), and (c)

34) The equilibrium position corresponds to which letter on the graph of G vs f (course of reaction) below?



A) A
B) B
C) C
D) D
E) E

35) For the reaction

$$C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$$

$\Delta H° = 131.3$ kJ / mol and $\Delta S° = 133.6$ J / Kmol at 298 K. At temperatures greater than _____°C this reaction is spontaneous under standard conditions.

A) 273
B) 325
C) 552
D) 710
E) 983

36) For the reaction

$$C_2H_6(g) \rightarrow C_2H_4(g) + H_2(g)$$

$\Delta H°$ is +137 kJ / mol and $\Delta S°$ is +120 J / Kmol. This reaction is _____.

A) spontaneous at all temperatures
B) spontaneous only at high temperature
C) spontaneous only at low temperature
D) nonspontaneous at all temperatures

37) A reaction that is not spontaneous at low temperature can become spontaneous at high temperature if ΔH is _____ and ΔS is _____.

A) +, +
B) -, -
C) +, -
D) -, +
E) +, 0

38) For a reaction to be spontaneous under standard conditions at all temperatures, the signs of $\Delta H°$ and $\Delta S°$ must be _____ and _____, respectively.

A) +, +
B) +, -
C) -, +
D) -, -
E) +, 0

39) Given the following table of thermodynamic data,

Substance	$\Delta H_f°$ (kJ/mol)	$S°$ (J/mol • K)
PCl_3 (g)	-288.07	311.7
PCl_3 (l)	-319.6	217

complete the following sentence. The vaporization of $PCl_3(l)$ is _____.

A) nonspontaneous at low temperature and spontaneous at high temperature
B) spontaneous at low temperature and nonspontaneous at high temperature
C) spontaneous at all temperatures
D) nonspontaneous at all temperatures
E) not enough information given to draw a conclusion

40) Given the following table of thermodynamic data,

Substance	$\Delta H_f°$ (kJ/mol)	$S°$ (J/mol • K)
$TiCl_4$ (g)	-763.2	354.9
$TiCl_4$ (l)	-804.2	221.9

complete the following sentence. The vaporization of $TiCl_4$ is _____.

A) spontaneous at all temperatures
B) spontaneous at low temperature and nonspontaneous at high temperature
C) nonspontaneous at low temperature and spontaneous at high temperature
D) nonspontaneous at all temperatures
E) not enough information given to draw a conclusion

41) Consider the reaction:

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$

Given the following table of thermodynamic data,

Substance	$\Delta H_f°$ (kJ/mol)	$S°$ (J/mol • K)
Ag^+ (aq)	105.90	73.93
Cl^- (aq)	-167.2	56.5
AgCl (s)	-127.0	96.11

determine the temperature (in °C) above which the reaction is nonspontaneous under standard conditions.

A) 1230
B) 150
C) 432
D) 133
E) 1640

42) Consider the reaction:

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

Given the following table of thermodynamic data,

Substance	$\Delta H_f°$ (kJ/mol)	$S°$ (J/mol • K)
NH_3 (g)	-46.19	192.5
HCl (g)	-92.30	186.69
NH_4Cl (s)	-314.4	94.6

determine the temperature (in °C) above which the reaction is nonspontaneous.

A) This reaction is spontaneous at all temperatures.
B) 618.1
C) 432.8
D) 345.0
E) 1235

43) Consider the reaction:

$$FeO(s) + Fe(s) + O_2(g) \rightarrow Fe_2O_3(s)$$

Given the following table of thermodynamic data,

Substance	$\Delta H_f°$ (kJ/mol)	$S°$ (J/mol • K)
FeO (s)	-271.9	60.75
Fe (s)	0	27.15
O_2 (g)	0	205.0
Fe_2O_3 (s)	-822.16	89.96

determine the temperature (in °C) above which the reaction is nonspontaneous.

A) This reaction is spontaneous at all temperatures.

B) 618.1
C) 756.3
D) 2438
E) 1235

44) With thermodynamics, one cannot determine _____.

A) the speed of a reaction
B) the direction of a spontaneous reaction
C) the extent of a reaction
D) the value of the equilibrium constant
E) the temperature at which a reaction will be spontaneous

45) If $\Delta G°$ for a reaction is greater than zero, then _____.

A) K = 0
B) K = 1
C) K > 1
D) K < 1
E) More information is needed.

46) Which one of the following statements is true about the equilibrium constant for a reaction if $\Delta G°$ for the reaction is negative?

A) K = 0
B) K = 1
C) K > 1
D) K < 1
E) More information is needed.

19.3 Short Answer Questions

1) A reversible change produces the maximum amount of _____ that can be achieved by the system on the surroundings.

2) Calculate $\Delta G°$ (in kJ/mol) for the following reaction at 1 atm and $25\ °C$:

$C_2H_6(g) + O_2(g) \rightarrow CO_2(g) + H_2O(l)$ (unbalanced)

$\Delta G_f\,°\,C_2H_6(g) = -32.89 KJ/mol$;

$\Delta G_f\,°\,CO_2(g) = -394.4$ kJ/mol;

$\Delta G_f\,°\,H_2O(l) = -237.13$ kJ/mol

3) Calculate $\Delta G°$ (in kJ/mol) for the following reaction at 1 atm and $25\ °C$:

$C_2H_6(g) + O_2(g) \rightarrow CO_2(g) + H_2O(l)$(unbalanced)

$\Delta H_f\,°\,C_2H6\ (g) = -84.7$ kJ/mol;

$S°\,C_2H_6(g) = 229.5$ J/K • mol;

$\Delta H_f\,°\,CO_2(g) = -393.5$ kJ/mol;

$S°\,CO_2(g) = 213.6$ J / K • mol;

$\Delta H_f\,°\,H_2O(l) = -285.8$ kJ/mol;

$S°\ H_2O\ (l) = 69.9$ J/K • mol;

$S°\,O_2(g) = 205.0$ J/K • mol

4) Find the temperature (in K) above which a reaction with a ΔH of $123.0 kJ / mol$ and a ΔS of $90.00 J / K \bullet mol$ becomes spontaneous.

5) Find the temperature (in K) above which a reaction with a ΔH of $53.00 kJ / mol$ and a ΔS of $100.0 J / K \bullet mol$ becomes spontaneous.

6) Calculate $\Delta G°$ for the autoionization of water at $25\ °C$. $K_W = 1.0 \times 10^{-14}$

19.4 True/False Questions

1) The melting of a substance at its melting point is an isothermal process.

2) The vaporization of a substance at its boiling point is an isothermal process

3) The quantity of energy gained by a system equals the quantity of energy gained by its surroundings.

4) The entropy of a pure crystalline substance at $0\ °C$ is zero.

5) The more negative $\Delta G°$ is for a given reaction, the larger the value of the corresponding equilibrium constant, K.

19.5 Algorithmic Questions

Chemistry, 11e (Brown/LeMay/Brusten/Murphy)
Chapter 19: Chemical Thermodynamics

1) The normal boiling point of methanol is 64.7 °C and the molar enthalpy of vaporization if 71.8 kJ/mol. The value of ΔS when 2.15 mol of $CH_3COH(l)$ vaporizes at 64.7 °C is _____ J/K.

A) 0.457
B) 5.21×10^7
C) 457
D) 2.39×10^3
E) 2.39

2) The value of $\Delta G°$ at 141.0 °C for the formation of phosphorous trichloride from its constituent elements,

$$P_2(g)+3Cl_2(g) \rightarrow 2PCl_3(g)$$

is _____ kJ/mol. At 25.0 °C for this reaction, $\Delta H°$ is $-720.5 kJ/mol$, $\Delta G°$ is -642.9 kJ/mol and $\Delta S°$ is -263.7 J/k.

A) -612.3
B) 3.65×10^4
C) 1.08×10^5
D) -683.3
E) -829.7

3) The value of $\Delta G°$ at 100.0 °C for the formation of calcium chloride from its constituent elements:

$$Ca(s)+Cl_2(g) \rightarrow CaCl_2(s)$$

is _____ kJ/mol. At 25.0 °C for this reaction, $\Delta H°$ is -795.8 kJ/mol, $\Delta G°$ is -748.1 kJ/mol, and $\Delta S°$ is -159.8 J/k

A) -855.4
B) -736.1
C) 5.88×10^4
D) -779.8
E) 1.52×10^4

4) For a given reaction, ΔH = -19.9 kJ/mol and ΔS = -55.5 J/K-mol. The reaction will have $\Delta G = 0$ at _____ K. at Assume that ΔH and ΔS do not vary with temperature.

A) 359
B) 2789
C) 298
D) 2.79
E) 0.359

5) For a given reaction, $\Delta H = +35.5 kJ/mol$ and $\Delta S = +83.6 J/K-mol$. The reaction is spontaneous _____. Assume that ΔH and ΔS do not vary with temperature.

A) at T < 425 K
B) at T > 425 K
C) at all temperatures
D) at T > 298 K
E) at T < 298 K

6) In the Haber process, ammonia is synthesized from nitrogen and hydrogen:

$$N_2(g)+3H_2(g) \rightarrow 2NH_3(g)$$

$\Delta G°$ at 298 K for this reaction is -33.3 kJ/mol. The value of ΔG at 298 K for a reaction mixture that consists of 1.9 atm N_2, 1.6 atm H_2, and 0.65 atm NH_3 is _____.

A) -1.8
B) -3.86×10^3
C) -7.25×10^3
D) -104.5
E) -40.5

7) Phosphorous and chlorine gases combine to produce phosphorous trichloride:

$$P_2(g)+3Cl_2(g) \rightarrow 2PCl_3(g)$$

$\Delta G°$ at 298 K for this reaction is -642.9 kJ/mol. The value of ΔG at 298 K for a reaction mixture that consists of 1.5 atm P_2 1.6 atm Cl_2 and 0.65 atm PCl_3 is _____.

A) -44.2
B) -3.88×10^3
C) -7.28×10^3
D) -708.4
E) -649.5