I. Entropy & the Second Law of Thermodynamics

1) A reaction that is spontaneous __________.
   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

2) 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

3) 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.

4) Of the following, only __________ is not a state function.
   A) S
   B) H
   C) q
   D) E
   E) T

5) 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

6) For an isothermal process, \( \Delta S = \_\_\_\_\_\_\_. \) *
7) Which one of the following is always positive when a spontaneous process occurs?

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

8) The entropy of the universe is __________.

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

9) The second law of thermodynamics states that __________.

A) $\Delta E = q + w$
B) $\Delta H_{\text{rxn}} = \Sigma n\Delta H_f^\circ \text{ (products)} - \Sigma m\Delta H_f^\circ \text{ (reactants)}$
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) $\Delta S = q_{\text{rev}}/T$ at constant temperature

10) 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.

11) Of the following, the entropy of __________ is the largest.

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

12) Of the following, the entropy of gaseous __________ is the largest at 25°C and 1 atm.
13) The entropy of a pure crystalline substance at 0°C is zero.
A) True
B) False

14) The quantity of energy gained by a system equals the quantity of energy gained by its surroundings.
A) True
B) False

II. Changes in Entropy

15) 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

16) ΔS is positive for the reaction __________.
A) 2H₂(g) + O₂(g) → 2H₂O(g)
B) 2NO(g) → N₂O₄(g)
C) CO₂(g) → CO₂(s)
D) BaF₂(s) → Ba²⁺ + 2F⁻(aq)
E) 2Hg(l) + O₂(g) → 2HgO(s)

17) ΔS is positive for the reaction __________.
A) CaO(s) + CO₂(g) → CaCO₃(s)
B) N₂(g) + 3H₂(g) → 2NH₃(g)
C) 2SO₃(g) → 2SO₂(g) + O₂(g)
D) Ag⁺(aq) + Cl⁻(aq) → AgCl(s)
E) H₂O(l) → H₂O(g)

18) Which reaction produces a decrease in the entropy of the system?
A) CaCO₃(s) → CaO(s) + CO₂(g)
B) 2C(s) + O₂(g) → 2CO(g)
C) CO₂(s) → CO₂(g)
D) 2H₂(g) + O₂(g) → 2H₂O(ℓ)
E) H₂O(ℓ) → H₂O(g)
19) Which reaction produces an increase in the entropy of the system?

A) Ag\(^{+}\)(aq) + Cl\(^{-}\)(aq) → AgCl(s)
B) CO\(_2\)(s) → CO\(_2\)(g)
C) H\(_2\)(g) + Cl\(_2\)(g) → 2HCl(g)
D) N\(_2\)(g) + 3H\(_2\)(g) → 2NH\(_3\)(g)
E) H\(_2\)O(l) → H\(_2\)O(s)

20) 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

21) \(\Delta S\) is negative for the reaction ----

A) 2SO\(_2\)(g) + O\(_2\)(g) → 2SO\(_3\)(g)
B) NH\(_4\)Cl(s) → NH\(_3\)(g) + HCl(g)
C) PbCl\(_2\)(s) → Pb\(^{2+}\) + 2Cl\(^{-}\)
D) 2C(s) + 2O\(_2\)(g) → 2CO\(_2\)(g)
E) H\(_2\)O(l) → H\(_2\)O(g)

22) \(\Delta S\) is negative for the reaction __________.

A) 2H\(_2\)O(g) → 2H\(_2\)(g) + O\(_2\)(g)
B) Mg(NO\(_3\))\(_2\)(aq) + 2NaOH(aq) → Mg(OH)\(_2\)(s) + 2NaNO\(_3\)(aq)
C) H\(_2\)O(l) → H\(_2\)O(g)
D) C\(_6\)H\(_12\)O\(_6\)(s) → 6C(s) + 6H\(_2\)(g) + 3O\(_2\)(g)
E) NaCl(aq) → Na\(^+\)(aq) + Cl\(^-\)(aq)

23) \(\Delta S\) is positive for the reaction __________.

A) Pb(NO\(_3\))\(_2\)(aq) + 2KI(aq) → Pbl\(_2\)(s) + 2KNO\(_3\)(aq)
B) 2H\(_2\)O(g) → 2H\(_2\)(g) + O\(_2\)(g)
C) H\(_2\)O(g) → H\(_2\)O(s)
D) NO(g) + O\(_2\)(g) → NO\(_2\)(g)
E) Ag\(^+\)(aq) + Cl\(^-\)(aq) → AgCl(s)

24) 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

III. Calculating changes in entropy
Use the table below to answer the next 5 questions.

<table>
<thead>
<tr>
<th>Substance</th>
<th>ΔH° (kJ/mol)</th>
<th>ΔG° (kJ/mol)</th>
<th>S (J/K·mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C (s, diamond)</td>
<td>1.88</td>
<td>2.84</td>
<td>2.43</td>
</tr>
<tr>
<td>C (s, graphite)</td>
<td>0</td>
<td>0</td>
<td>5.69</td>
</tr>
<tr>
<td>C₂H₂ (g)</td>
<td>226.7</td>
<td>209.2</td>
<td>200.8</td>
</tr>
<tr>
<td>C₂H₄ (g)</td>
<td>52.30</td>
<td>68.11</td>
<td>219.4</td>
</tr>
<tr>
<td>C₂H₆ (g)</td>
<td>-84.68</td>
<td>-32.89</td>
<td>229.5</td>
</tr>
<tr>
<td>CO (g)</td>
<td>-110.5</td>
<td>-37.2</td>
<td>197.9</td>
</tr>
<tr>
<td>CO₂ (g)</td>
<td>-393.5</td>
<td>-394.4</td>
<td>213.6</td>
</tr>
<tr>
<td>Hydrogen</td>
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<td></td>
<td></td>
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<tr>
<td>H₂ (g)</td>
<td>0</td>
<td>0</td>
<td>130.58</td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂ (g)</td>
<td>0</td>
<td>0</td>
<td>205.0</td>
</tr>
<tr>
<td>H₂O (l)</td>
<td>-258.83</td>
<td>-237.13</td>
<td>69.91</td>
</tr>
</tbody>
</table>

25) The value of ΔS° for the catalytic hydrogenation of acetylene to ethane is _____ J/K·mol.

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

26) The combustion of acetylene in the presence of excess oxygen yields carbon dioxide and water is shown below. The value of ΔS° for this reaction is __________ J/K·mol.

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

27) The value of ΔS° for the oxidation of carbon to carbon dioxide,

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

28) What is the value of ΔS°, in J/K·mol, for this reaction: the combustion of ethene in the presence of excess oxygen yielding carbon dioxide and water:
\[
\text{C}_2\text{H}_4(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})
\]

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

29) The combustion of ethane in the presence of excess oxygen yields carbon dioxide and water. The value of \(\Delta S^\circ\) for this reaction is \(\underline{\text{__________}}\) J/K \(\cdot\) mol.

\[
2\text{C}_2\text{H}_6(\text{g}) + 7\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{l})
\]

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

Use the table below to answer the next 5 questions.

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

<table>
<thead>
<tr>
<th>Substance</th>
<th>(\Delta H^\circ) (kJ/mol)</th>
<th>(\Delta G^\circ) (kJ/mol)</th>
<th>(S^\circ) (J/K (\cdot) mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca (s)</td>
<td>0</td>
<td>0</td>
<td>41.4</td>
</tr>
<tr>
<td>CaCl_2 (s)</td>
<td>-795.8</td>
<td>-748.1</td>
<td>104.6</td>
</tr>
<tr>
<td>Ca^{2+} (aq)</td>
<td>226.7</td>
<td>209.2</td>
<td>200.8</td>
</tr>
<tr>
<td>Chlorine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl_2 (g)</td>
<td>0</td>
<td>0</td>
<td>222.96</td>
</tr>
<tr>
<td>Cl^-</td>
<td>-167.2</td>
<td>-131.2</td>
<td>56.5</td>
</tr>
<tr>
<td>CO_2 (g)</td>
<td>-393.5</td>
<td>-394.4</td>
<td>213.6</td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O_2 (g)</td>
<td>0</td>
<td>0</td>
<td>205.0</td>
</tr>
<tr>
<td>H_2O (l)</td>
<td>-258.83</td>
<td>-237.13</td>
<td>69.91</td>
</tr>
<tr>
<td>Phosphorous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P_2 (g)</td>
<td>144.3</td>
<td>103.7</td>
<td>218.1</td>
</tr>
<tr>
<td>PCl_3</td>
<td>-288.1</td>
<td>-269.6</td>
<td>311.7</td>
</tr>
<tr>
<td>POCl_3 (g)</td>
<td>-542.2</td>
<td>-502.5</td>
<td>325</td>
</tr>
<tr>
<td>Sulfur</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S (s, rhombic)</td>
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<td>0</td>
<td>31.88</td>
</tr>
<tr>
<td>SO_2 (g)</td>
<td>-269.9</td>
<td>-300.4</td>
<td>248.5</td>
</tr>
<tr>
<td>SO_3 (g)</td>
<td>-395.2</td>
<td>-370.4</td>
<td>256.2</td>
</tr>
</tbody>
</table>

30) The value of \(\Delta S^\circ\) for the oxidation of solid elemental sulfur to gaseous sulfur trioxide, as shown below, is \(\underline{\text{__________}}\) J/K \(\cdot\) mol.

\[
2\text{S(s, rhombic)} + 3\text{O}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g})
\]

A) +19.3  
B) -19.3  
C) +493.1  
D) -166.4  
E) -493.1
31) The value of $\Delta S^o$ for the decomposition of gaseous sulfur trioxide to solid elemental sulfur and gaseous oxygen, as shown below, is __________ J/K·mol.

$$2\text{SO}_3(g) \rightarrow 2\text{S(s, rhombic)} + 3\text{O}_2(g)$$

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

32) The value of $\Delta S^o$ for the formation of $\text{POCl}_3$ from its constituent elements, as shown below, is __________ J/K·mol.

$$\text{P}_2(g) + \text{O}_2(g) + 3\text{Cl}_2(g) \rightarrow 2\text{POCl}_3(g)$$

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

33) The value of $\Delta S^o$ for the decomposition of $\text{POCl}_3$ into its constituent elements, as shown below is __________ J/K·mol.

$$2\text{POCl}_3(g) \rightarrow \text{P}_2(g) + \text{O}_2(g) + 3\text{Cl}_2(g)$$

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

34) The value of $\Delta S^o$ for the formation of calcium chloride from its constituent elements, as shown below, is __________ J/K·mol.

$$\text{Ca}(s) + \text{Cl}_2(g) \rightarrow \text{CaCl}_2(s)$$

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

IV. Gibbs free energy

35) The standard Gibbs free energy of formation of __________ is zero. *

(I) H$_2$O(l)    (II) O(g)    (III) H$_2$(g)

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

36) The standard Gibbs free energy of formation of __________ is zero.[*

(I) H$_2$O(l)    (II) Na(s)    (III) H$_2$(g)
A) I only
B) II only
C) III only
D) II and III
E) I, II, and III

37) The standard Gibbs free energy of formation of __________ is zero. *
   (I) Al (s)    (II) Br₂ (l)    (III) Hg (l)
   A) I only
   B) II only
   C) III only
   D) II and III
   E) I, II, and III

Use the table below to answer the next 4 questions. **

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

<table>
<thead>
<tr>
<th>Substance</th>
<th>ΔH°f (kJ/mol)</th>
<th>ΔG°f (kJ/mol)</th>
<th>S (J/K·mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca (s)</td>
<td>0</td>
<td>0</td>
<td>41.4</td>
</tr>
<tr>
<td>CaCl₂ (s)</td>
<td>-795.8</td>
<td>-748.1</td>
<td>104.6</td>
</tr>
<tr>
<td>Ca²⁺ (aq)</td>
<td>226.7</td>
<td>209.2</td>
<td>200.8</td>
</tr>
<tr>
<td>Chlorine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl₂ (g)</td>
<td>0</td>
<td>0</td>
<td>222.96</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>-167.2</td>
<td>-131.2</td>
<td>56.5</td>
</tr>
<tr>
<td>CO₂ (g)</td>
<td>-393.5</td>
<td>-394.4</td>
<td>213.6</td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂ (g)</td>
<td>0</td>
<td>0</td>
<td>205.0</td>
</tr>
<tr>
<td>H₂O (l)</td>
<td>-258.83</td>
<td>-237.13</td>
<td>69.91</td>
</tr>
<tr>
<td>Phosphorous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P₂ (g)</td>
<td>144.3</td>
<td>103.7</td>
<td>218.1</td>
</tr>
<tr>
<td>PCl₃</td>
<td>-288.1</td>
<td>-269.6</td>
<td>311.7</td>
</tr>
<tr>
<td>POCl₃ (g)</td>
<td>-542.2</td>
<td>-502.5</td>
<td>325</td>
</tr>
<tr>
<td>Sulfur</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S (s, rhombic)</td>
<td>0</td>
<td>0</td>
<td>31.88</td>
</tr>
<tr>
<td>SO₂ (g)</td>
<td>-269.9</td>
<td>-300.4</td>
<td>248.5</td>
</tr>
<tr>
<td>SO₃ (g)</td>
<td>-395.2</td>
<td>-370.4</td>
<td>256.2</td>
</tr>
</tbody>
</table>

38) The value of ΔG° at 25°C for the decomposition of gaseous sulfur trioxide to solid elemental sulfur and gaseous oxygen, as shown below, is __________ kJ/mol.
   \[2\text{SO}_3(g) \rightarrow 2\text{S(s, rhombic)} + 3\text{O}_2(g)\]
   A) +740.8
   B) -370.4
   C) +370.4
   D) -740.8
   E) +185.2

39) The value of ΔG° at 25°C for the decomposition of gaseous sulfur dioxide to solid elemental sulfur and gaseous oxygen,, as shown below, is __________ kJ/mol.
SO₂(g) → S(s, rhombic) + O₂(g)

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

40) The value of ΔG° at 25°C for the formation of POCl₃ from its constituent elements, as shown below, is __________ kJ/mol.
P₂(g) + O₂(g) + 3Cl₂(g) → 2POCl₃(g)

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

41) The value of ΔG° at 25°C for the formation of phosphorous trichloride from its constituent elements, as shown below, is __________ kJ/mol.
P₂(g) + 3Cl₂(g) → 2PCl₃(g)

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

42) The value of ΔG° at 373 K for the oxidation of solid elemental sulfur to gaseous sulfur dioxide, as shown below, is __________ kJ/mol. At 298 K, ΔH° for this reaction is -269.9 kJ/mol, and ΔS° is +11.6 J/K.

S(s, rhombic) + O₂(g) → SO₂(g)

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

V. Gibbs Free Energy and Temperature

43) 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 temperature at which a reaction will be spontaneous

44) For the reaction shown below, ΔH° is +137 kJ/mol and ΔS° is +120 J/mol. This reaction is __________.
C\textsubscript{2}H\textsubscript{6}(g) \rightarrow C\textsubscript{2}H\textsubscript{4}(g) + H\textsubscript{2}(g)

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

45) A reaction that is not spontaneous at low temperature can become spontaneous at high temperature if \( \Delta H \) is \__________ and \( \Delta S \) is \__________.

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

46) For a reaction to be spontaneous under standard conditions at all temperatures, the signs of \( \Delta H^o \) and \( \Delta S^o \) must be \__________ and \__________, respectively.

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

47) For the below reaction, \( \Delta H^o = 131.3 \text{ kJ/mol} \) and \( \Delta S^o = 133.6 \text{ J/mol} \) at 298 K. At temperatures greater than \_________°C this reaction is spontaneous under standard conditions

\[ \text{C(s) + H}_2\text{O(g)} \rightarrow \text{CO(g) + H}_2\text{(g)} \]

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

48) Find the temperature (in K) above which a reaction with a \( \Delta H \) of 123.0 kJ/mol and a \( \Delta S \) of 90.00 J/mol\,K becomes spontaneous.

49) Find the temperature (in K) above which a reaction with a \( \Delta H \) of 53.00 kJ/mol and a \( \Delta S \) of 100.0 J/mol\,K becomes spontaneous.

50) Given the following table of thermodynamic data, complete the following sentence. The vaporization of PCl\textsubscript{3}(l) is \__________.
<table>
<thead>
<tr>
<th>Substance</th>
<th>$\Delta H^\circ_f$ (kJ/mol)</th>
<th>$S^\circ$ (J/K·mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCl$_3$ (g)</td>
<td>-288.07</td>
<td>311.7</td>
</tr>
<tr>
<td>PCl$_3$ (l)</td>
<td>-319.6</td>
<td>217</td>
</tr>
</tbody>
</table>

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

51) Given the following table of thermodynamic data, complete the following sentence. The vaporization of TiCl$_4$ is __________.

<table>
<thead>
<tr>
<th>Substance</th>
<th>$\Delta H^\circ_f$ (kJ/mol)</th>
<th>$S^\circ$ (J/K·mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiCl$_4$ (g)</td>
<td>-763.2</td>
<td>354.9</td>
</tr>
<tr>
<td>TiCl$_4$ (l)</td>
<td>-804.2</td>
<td>221.9</td>
</tr>
</tbody>
</table>

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

52) Consider the reaction: $\text{Ag}^+(aq) + \text{Cl}^-(aq) \rightarrow \text{AgCl}(s)$

Given the following table of thermodynamic data, determine the temperature (in °C) above which the reaction is nonspontaneous under standard conditions.

<table>
<thead>
<tr>
<th>Substance</th>
<th>$\Delta H^\circ_f$ (kJ/mol)</th>
<th>$S^\circ$ (J/K·mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Ag}^+(aq)$</td>
<td>105.90</td>
<td>73.93</td>
</tr>
<tr>
<td>$\text{Cl}^-(aq)$</td>
<td>-167.2</td>
<td>56.50</td>
</tr>
<tr>
<td>$\text{AgCl}(s)$</td>
<td>-127.0</td>
<td>96.11</td>
</tr>
</tbody>
</table>

A) 1230  
B) 150  
C) 432  
D) 133  
E) 1640
53) Consider the reaction: \( \text{NH}_3(g) + \text{HCl}(g) \rightarrow \text{NH}_4\text{Cl}(s) \)

Given the following table of thermodynamic data, determine the temperature (in °C) above which the reaction is nonspontaneous.

<table>
<thead>
<tr>
<th>Substance</th>
<th>( \Delta H^\circ_f ) (kJ/mol)</th>
<th>( S^\circ ) (J/K·mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{NH}_3(g) )</td>
<td>-46.19</td>
<td>192.50</td>
</tr>
<tr>
<td>( \text{HCl}(g) )</td>
<td>-92.30</td>
<td>186.69</td>
</tr>
<tr>
<td>( \text{NH}_4\text{Cl}(s) )</td>
<td>-314.40</td>
<td>94.60</td>
</tr>
</tbody>
</table>

A) Spontaneous at all temperatures
B) 300
C) 323
D) 345
E) 245

54) Consider the reaction: \( \text{FeO}(s) + \text{Fe}(s) + \text{O}_2(g) \rightarrow \text{Fe}_2\text{O}_3(s) \)

Given the following table of thermodynamic data, determine the temperature (in °C) above which the reaction is nonspontaneous.

<table>
<thead>
<tr>
<th>Substance</th>
<th>( \Delta H^\circ_f ) (kJ/mol)</th>
<th>( S^\circ ) (J/K·mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{FeO}(s) )</td>
<td>-271.9</td>
<td>60.75</td>
</tr>
<tr>
<td>( \text{Fe}(s) )</td>
<td>0</td>
<td>27.15</td>
</tr>
<tr>
<td>( \text{O}_2(g) )</td>
<td>0</td>
<td>205.00</td>
</tr>
<tr>
<td>( \text{Fe}_2\text{O}_3(s) )</td>
<td>-822.16</td>
<td>89.96</td>
</tr>
</tbody>
</table>

A) Spontaneous at all temperatures
B) 618.1
C) 756.3
D) 2438
E) 1235
## ANSWERS

<table>
<thead>
<tr>
<th>I.</th>
<th>II.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  B</td>
<td>15  D</td>
</tr>
<tr>
<td>2  A</td>
<td>16  D</td>
</tr>
<tr>
<td>3  C</td>
<td>17  C</td>
</tr>
<tr>
<td>4  C</td>
<td>18  D</td>
</tr>
<tr>
<td>5  D</td>
<td>19  B</td>
</tr>
<tr>
<td>6  B</td>
<td>20  C</td>
</tr>
<tr>
<td>7  C</td>
<td>21  A</td>
</tr>
<tr>
<td>8  C</td>
<td>22  B</td>
</tr>
<tr>
<td>9  C</td>
<td>23  B</td>
</tr>
<tr>
<td>10 A</td>
<td>24  E</td>
</tr>
<tr>
<td>11 E</td>
<td>25  D</td>
</tr>
<tr>
<td>12 B</td>
<td>26  E</td>
</tr>
<tr>
<td>13 False</td>
<td>27  E</td>
</tr>
<tr>
<td>14 False</td>
<td>28  A</td>
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<tr>
<td>29 B</td>
<td>29 B</td>
</tr>
<tr>
<td>30 D</td>
<td>31 D</td>
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<td>33 B</td>
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<td>35 C</td>
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<tr>
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<td>37 E</td>
</tr>
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<td>38 A</td>
<td>39 D</td>
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<tr>
<td>40 A</td>
<td>41 C</td>
</tr>
<tr>
<td>42 E</td>
<td>43 A</td>
</tr>
<tr>
<td>44 B</td>
<td>45 A</td>
</tr>
<tr>
<td>46 C</td>
<td>47 D</td>
</tr>
<tr>
<td>48 1367 K</td>
<td>49 530 K</td>
</tr>
<tr>
<td>50 A</td>
<td>51 C</td>
</tr>
<tr>
<td>52 E</td>
<td>53 D</td>
</tr>
<tr>
<td>54 D</td>
<td></td>
</tr>
</tbody>
</table>