

MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.

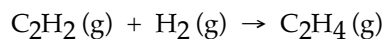
- 1) The thermodynamic quantity that expresses the degree of disorder in a system is _____.
- A) entropy
 - B) internal energy
 - C) heat flow
 - D) enthalpy
 - E) bond energy
- 2) Which one of the following is always positive when a spontaneous process occurs?
- A) ΔH_{univ} B) ΔH_{surr} C) ΔS_{surr} D) ΔS_{univ} E) ΔS_{sys}
- 3) ΔS will be positive for the reaction _____.
- A) $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g})$
 - B) $2\text{NO}_2(\text{g}) \rightarrow \text{N}_2\text{O}_4(\text{g})$
 - C) $\text{BaF}_2(\text{s}) \rightarrow \text{Ba}^{2+}(\text{aq}) + 2\text{F}^{-}(\text{aq})$
 - D) $2\text{Hg}(\text{l}) + \text{O}_2(\text{g}) \rightarrow 2\text{HgO}(\text{s})$
 - E) $\text{CO}_2(\text{g}) \rightarrow \text{CO}_2(\text{s})$
- 4) Which one of the following processes produces a decrease in the entropy of the system?
- A) dissolution of solid KCl in water
 - B) mixing of two gases into one container
 - C) freezing water to form ice
 - D) melting ice to form water
 - E) boiling water to form steam
- 5) Of the following, the entropy of gaseous _____ is the largest at 25°C and 1 atm.
- A) C_2H_2 B) H_2 C) C_2H_6 D) CH_4 E) C_2H_2

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 ₂ H ₂ (g)	226.7	209.2	200.8
C ₂ H ₄ (g)	52.30	68.11	219.4
C ₂ H 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 ₂ O (l)	-285.83	-237.13	69.91

6) The value of ΔS° for the catalytic hydrogenation of acetylene to ethene,



is _____ J/K.

A) -18.6

B) +18.6

C) +112.0

D) +550.8

E) -112.0

7) What can be said about a chemical system that has reached a minimum in free energy?

A) The reaction is complete.

B) The system entropy is zero.

C) The system has achieved equilibrium.

D) The temperature is OK.

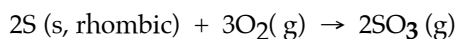
E) The reaction is very fast.

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)
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 ₂ O (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

8) The value of ΔH° for the oxidation of solid elemental sulfur to gaseous sulfur trioxide,



is _____ kJ/mol.

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

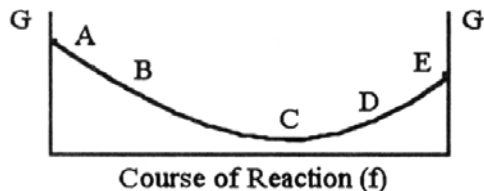
9) The value of ΔG° at 25°C for the formation of POCl₃ from its constituent elements,



is _____ kJ/mol.

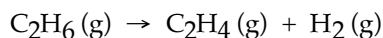
- A) -606.2 B) -1,005 C) +606.2 D) +1,109 E) -1,109

10) 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

11) For the reaction



ΔH° is +137 kJ/mol and ΔS° is +120 J/K · mol. This reaction is _____.

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

12) 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

13) For a reaction to be spontaneous under standard conditions at all temperatures, the signs of ΔH° and ΔS° must be _____ and _____, respectively.

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

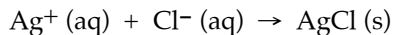
14) Given the following table of thermodynamic data,

Substance	ΔH_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 TiCl₄ is _____.

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

15) Consider the reaction:



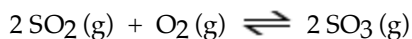
Given the following table of thermodynamic data,

Substance	ΔH_f° (kJ/mol)	S° (J/mol · K)
$\text{Ag}^+ (\text{aq})$	105.90	73.93
$\text{Cl}^- (\text{aq})$	-167.2	56.5
$\text{AgCl} (\text{s})$	-127.0	96.11

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

- A) 1235 B) 150.5 C) 432.8 D) 1641 E) 133.0

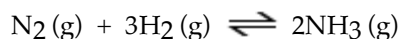
16) Given the thermodynamic data in the table below, calculate the equilibrium constant for the reaction:



Substance	ΔH_f° (kJ/mol)	Δ° (J/mol · K)
$\text{SO}_2 (\text{g})$	-297	249
$\text{O}_2 (\text{g})$	0	205
$\text{SO}_3 (\text{g})$	-395	256

- A) 1.06
B) 2.32×10^{24}
C) 3.82×10^{23}
D) 1.95
E) More data are needed.

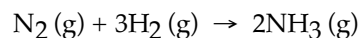
17) The equilibrium constant for the following reaction is 5.0×10^8 at 25°.



The value of ΔG° for this reaction is _____ kJ/mol.

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

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



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

Answer Key

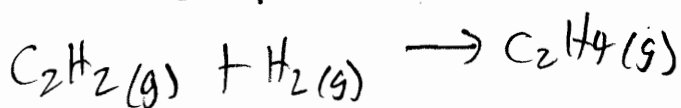
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MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.

- 1) A
ID: chem9b 19.1-8
- 2) D
ID: chem9b 19.1-10
- 3) C
ID: chem9b 19.1-15
- 4) C
ID: chem9b 19.1-16
- 5) C
ID: chem9b 19.1-26
- 6) E
ID: chem9b 19.1-27
- 7) C
ID: chem9b 19.1-47
- 8) E
ID: chem9b 19.1-50
- 9) E
ID: chem9b 19.1-64
- 10) C
ID: chem9b 19.1-71
- 11) C
ID: chem9b 19.1-74
- 12) A
ID: chem9b 19.1-75
- 13) C
ID: chem9b 19.1-76
- 14) D
ID: chem9b 19.1-78
- 15) D
ID: chem9b 19.1-79
- 16) B
ID: chem9b 19.1-83
- 17) A
ID: chem9b 19.1-87
- 18) C
ID: chem9b 19.2-9

CH. 16
Practice
Test
A.P. Chemistry
Entropy,
Free Energy,
Reaction
Spontaneity

$$\textcircled{6} \Delta S^\circ = \sum S^\circ_{\text{products}} - \sum S^\circ_{\text{reactants}}$$



$$\Delta S^\circ = (219.4) - [200.8 + 130.58]$$

$$= 219.4 - 331.38$$

$$= -111.98 = -112.05/\text{kind}$$

$$\textcircled{8} \Delta H^\circ = \sum \Delta H_f^\circ \text{ PRODUCTS} - \sum \Delta H_f^\circ \text{ REACTANTS}$$

$$= [(2)(-395.2)] - [(2)(0) + (3)(0)]$$

$$= -790.4 \text{ kJ/mol}$$

$$\textcircled{9} \Delta G^\circ = [\text{PRODUCTS}] - [\text{REACTANTS}]$$

$$= [(2)(-502.5)] - [(103.7) + (0) + (0)]$$

$$= -1108.7 \text{ kJ/mol}$$

$\textcircled{11}$ ΔH is + and is unfavorable
 ΔS is + and is favorable

Such rxns are spontaneous at high temps.

For this rxn, for instance, the cut-off temp between spontaneous (ΔG is -) and nonspontaneous (ΔG is +) is 1142 K.

$$\Delta G = 0 = \Delta H - T\Delta S$$

$$\Delta H = T\Delta S \rightarrow T = \frac{\Delta H}{\Delta S} = \frac{137000 \text{ J}}{120 \frac{\text{J}}{\text{K}}} = 1142 \text{ K}$$

(continue)
→

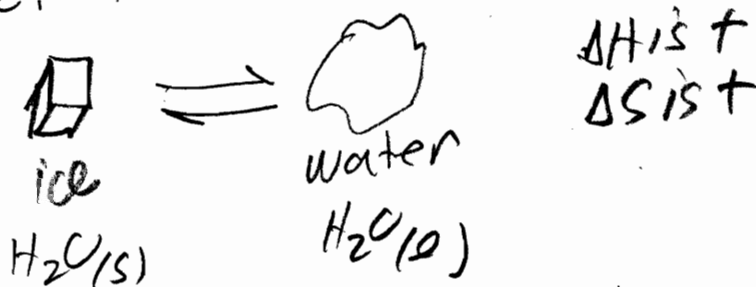
(11) so, at 1142K, $\Delta G = 0$

PAGE
TWO

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

any temp higher than 1142 would make the product " $T\Delta S$ " greater, and thus ΔG would become increasingly negative the higher the temp goes. On the other hand, as T decreases below 1142K, the " $T\Delta S$ " term decreases, making the difference of " $\Delta H - T\Delta S$ " become a more positive number.

(12) A: ΔH is + and ΔS is +. For example, see #11 above.
another example:

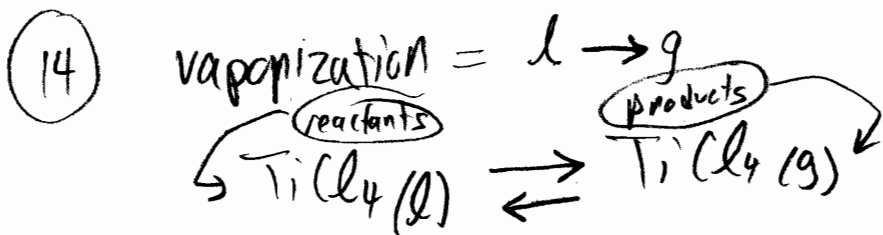


As rxn proceeds to the right, ΔH is +
Note: you must heat the ice cube to melt it, so
from the perspective of the ice cube heat
is absorbed.

As rxn proceeds to right, randomness increases,
so ΔS is + spontaneously

Ice melts spontaneously at high temps, but not below $0^\circ C$.
Thus, when ΔH and ΔS are both +, the
reaction will only be spontaneous at high temps.

(13) ΔH is - (favorable)
 ΔS is + (favorable)



$$\Delta H^\circ = [-763.2] - [-804.2] = +41 \text{ kJ/mol}$$

$$\Delta S^\circ = [354.9] - [221.9] = +133 \text{ J/K}\cdot\text{mol}$$

NON spontaneous at low temps
and spontaneous at high temps.

} using signs on ΔH & ΔS .
This can also be calculated using $\Delta G = \Delta H - T\Delta S$

(15) $\Delta G = 0 = \Delta H - T\Delta S$

$$T\Delta S = \Delta H$$

$$T = \frac{\Delta H}{\Delta S} = \frac{-65700 \text{ J/mol}}{-34.32 \text{ J/K}\cdot\text{mol}} = 1914 \text{ K} = (1914 - 273)^\circ\text{C} = 1641^\circ\text{C}$$

$$\Delta H = [-127] - [-167.2 + 105.9] = -127 - (-61.3) = -65.7 \text{ kJ/mol}$$

$$\Delta S = [96.11] - [56.5 + 73.93] = 96.11 - 130.43 = -34.32 \text{ J/K}\cdot\text{mol}$$

(16) $\Delta H^\circ = [(2)(-395)] - [(2)(-297) + 0] = -790 - (-594) = -196 \text{ kJ/mol}$

$$\Delta S^\circ = [(2)(256)] - [(2)(249) + 205] = 512 - [498 + 205] = -191 \text{ J/K}\cdot\text{mol}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ = (-196000 \text{ J/mol}) - (298 \text{ K})(-191 \text{ J/mol}\cdot\text{K})$$

standard temp = 298K

$$= -196000 \text{ J/mol} + 56918 \text{ J/mol} = -139082 \text{ J/mol}$$

continued \rightarrow

(16) (continued)

$$\Delta G^{\circ} = -RT \ln K$$

$$-139082 = -\left(\frac{8.3145 \text{ J}}{\text{K mol}}\right)(298\text{K}) \ln K$$

$$\frac{-139082 \text{ J}}{-2477.72 \frac{\text{J}}{\text{mol}}} = 56.133 = \ln K$$

$$K = e^{56.133}$$

$$K = 2.39 \times 10^{24}$$

$$(17) \Delta G^{\circ} = -RT \ln K$$

$$\Delta G^{\circ} = -\left(\frac{8.3145 \text{ J}}{\text{K mol}}\right)(298\text{K}) \ln 5.0 \times 10^8$$

$$= -\frac{49629 \text{ J}}{\text{mol}} = -\frac{49.6 \text{ kJ}}{\text{mol}} = -50 = -5.0 \times 10^1 \text{ kJ/mol}$$

$$(18) \Delta G = \Delta G^{\circ} + RT \ln Q$$

$$= -\frac{33300 \text{ J}}{\text{mol}} + \left(\frac{8.3145 \text{ J}}{\text{K mol}}\right)(298\text{K}) \left(\ln \frac{(0.65)^2}{(1.9)(1.6)^3}\right)$$

$$= -\frac{33300 \text{ J}}{\text{mol}} + 2477.721 (\ln 0.054289) \frac{\text{J}}{\text{mol}}$$

$$= -\frac{33300 \text{ J}}{\text{mol}} + \frac{-7218.67 \text{ J}}{\text{mol}} = -40519 \text{ J/mol}$$

$$= -40.5 \text{ kJ/mol}$$