Name:
Period:

15.2 homework problems p. 247-263 (reading the section is such a good idea!!)

ENTROPY

Name _____

Entropy is the degree of randomness in a substance. The symbol for change in entropy is ΔS.

Solids are very ordered and have low entropy. Liquids and aqueous ions have more entropy because they move about more freely, and gases have an even larger amount of entropy. According to the Second Law of Thermodynamics, nature is always proceeding to a state of higher entropy.

Determine whether the following reactions show an increase or decrease in entropy.

1. $2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$ $+\Delta S$
2. $H_2O(l) \rightarrow H_2O(s)$ $-\Delta S$
3. $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$ $-\Delta S$
4. $NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$ $+\Delta S$
5. $KCl(s) \rightarrow KCl(l)$ $+\Delta S$
6. $CO_2(s) \rightarrow CO_2(g)$ $+\Delta S$
7. $H^+(aq) + C_2H_3O_2^-(aq) \rightarrow HC_2H_3O_3(l)$ $-\Delta S$
8. $C(s) + O_2(g) \rightarrow CO_2(g)$ $-\Delta S$ (less # of particles/moles)
9. $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$ $D \approx \Delta S$
10. $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$ $-\Delta S$
11. $2N_2O_5(g) \rightarrow 4NO_2(g) + O_2(g)$ $+\Delta S$
12. $2Al(s) + 3I_2(s) \rightarrow 2AlI_3(s)$ $-\Delta S$
13. $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$ $-\Delta S$
14. $2NO(g) \rightarrow N_2(g) + O_2(g)$ $D \approx \Delta S$
15. $H_2O(g) \rightarrow H_2O(l)$ $-\Delta S$

Name:_____
Period:_____

GIBBS FREE ENERGY

Name _____

For a reaction to be spontaneous, the sign of ΔG (Gibbs Free Energy) must be negative. The mathematical formula for this value is:

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

where ΔH = change in enthalpy or heat of reaction
T = temperature in Kelvin
ΔS = change in entropy or randomness

Complete the table for the sign of ΔG; +, – or undetermined. When conditions allow for an undetermined sign of ΔG, temperature will decide spontaneity.

ΔH	ΔS	ΔG
–	+	–
+	–	+
–	–	+/–
+	+	+/–

always
never
↑temp spon
↑temp always spon

Answer the questions below.

1. The conditions in which ΔG is always negative is when ΔH is negative and ΔS is positive.
2. The conditions in which ΔG is always positive is when ΔH is positive and ΔS is negative.
3. When the situation is indeterminate, a low temperature favors the (entropy / enthalpy) factor, and a high temperature favors the (entropy / enthalpy) factor.

Answer Problems 4-6 with always, sometimes or never.

4. The reaction: $Na(OH)_s \rightarrow Na^+(aq) + OH^-(aq)$ + exothermic energy will always be spontaneous.
5. The reaction: endothermic energy + $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$ will never be spontaneous.
6. The reaction: endothermic energy + $H_2O(s) \rightarrow H_2O(l)$ will sometimes be spontaneous.
7. What is the value of ΔG if ΔH = -32.0 kJ, ΔS = +25.0 kJ/K and T = 293 K? −7357
   −32 − (25 × 293) =
8. Is the reaction in Problem 7 spontaneous? yes!
9. What is the value of ΔG if ΔH = +12.0 kJ, ΔS = -5.00 kJ/K and T = 290. K? 1462
   12 − (−5 × 290)
10. Is the reaction in Problem 9 spontaneous? no!

Name:_____
Period:_____

Exercises

54 Identify the process expected to have a value of ΔS closest to zero?

B

A $C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$ $-\Delta S$
B $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$
C $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$ $+\Delta S$
D $H_2O(l) \rightarrow H_2O(g)$ $+\Delta S$

55 Identify the processes which have an associated increase in entropy.

C

I $Br_2(g) \rightarrow Br_2(l)$ $-\Delta S$
II $Br_2(g) \rightarrow 2Br(g)$ $+\Delta S$
III $KBr(s) \rightarrow K^+(aq) + Br^-(aq)$ $+\Delta S$

A I and II **B** I and III **C** II and III **D** I, II, and III

56 Which is the best description of the entropy and enthalpy changes accompanying the sublimation of iodine: $I_2(s) \rightarrow I_2(g)$? $+\Delta S$, $+\Delta H$

A

A ΔS +, ΔH +, reaction is endothermic
B ΔS +, ΔH −, reaction is exothermic
C ΔS −, ΔH +, reaction is endothermic
D ΔS −, ΔH −, reaction is exothermic

57 Identify the reaction which has the largest increase in entropy?

D

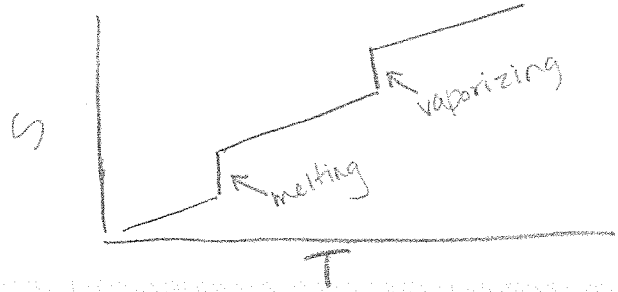
A $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$ $-\Delta S$
B $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$ $0 \approx \Delta S$
C $C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$ $-\Delta S$
D $Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$ $+\Delta S$

58 Predict the entropy change ΔS for the following reactions.

(a) $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$ $-\Delta S$
(b) $3Fe(s) + 4H_2O(g) \rightarrow Fe_3O_4(s) + 4H_2(g)$ $-\Delta S$
(c) $Ba(OH)_2{\cdot}8H_2O(s) + 2NH_4SCN(s) \rightarrow Ba(SCN)_2(aq) + 2NH_3(aq) + 10H_2O(l)$ $+\Delta S$

Exercises

59 Sketch a graph to show how the entropy of a solid changes as the temperature increases.



60 Calculate the entropy change ΔS for the Haber process, shown below, using tabulated standard molar entropies at 25 °C.

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

S → 191 3x(131) 2x(193)

$\Delta S = (2 \times 193) - ((3 \times 131) + 191)$

$= -198\ J/kmol$

Name:_____
Period:_____

61 Calculate the standard entropy change associated with the formation of methane from its elements.

$C_{(s)} + 2H_{2(g)} \rightarrow CH_{4(g)}$

$S \rightarrow \quad 5.7 \quad 2\times131 \quad 186$

$\Delta S = (186) - (5.7 + (2\times131))$

$= -82 J/K mol \quad (2 SF)$

Exercises

62 Ammonium chloride dissolves in water spontaneously in an endothermic process. Identify the best explanation for these observations.

A Endothermic processes are energetically favourable ✗ NO!

B The bonds in solid NH_4Cl are very weak. ionic - NOT true

C

C The entropy change of the system drives the process.

D The entropy change of the surroundings drives the process

Not surroundings

63 **(a)** Use data from section 12 of the IB data booklet and additional data ($\Delta H_f^\ominus(H_2O(s)) = -292$ kJ mol^{-1}) to calculate the enthalpy change that occurs when ice melts.

(b) The entropy change when ice melts is 22.0 J K^{-1} mol^{-1}. Deduce a value for the melting point of ice.

a) $H_2O_{(s)} \rightarrow H_2O_{(l)}$

$H \rightarrow -292 \qquad 70$

$\Delta H = 70 - (-292) = +6 KJ/mol$

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

$T = \Delta H / \Delta S$

$= +6 / .022$

$= 272.7 K \approx 0^\circ C$

Name:_____
Period:_____

64 Identify the combination of ΔH and ΔS which results in a reaction being spontaneous at low temperatures but non-spontaneous at higher temperatures?

A

A $\Delta S -$ and $\Delta H -$ **B** $\Delta S +$ and $\Delta H -$ **C** $\Delta S -$ and $\Delta H +$ **D** $\Delta S +$ and $\Delta H +$

65 Identify the combination of ΔH and ΔS which leads to a reaction that is **not** spontaneous at low temperatures but becomes spontaneous at higher temperatures?

D

A $\Delta H -$ and $\Delta S -$ **B** $\Delta H -$ and $\Delta S +$ **C** $\Delta H +$ and $\Delta S -$ **D** $\Delta H +$ and $\Delta S +$

66 The ΔH and ΔS values for the combustion of hydrogen are both negative. Which is the correct description of this reaction at different temperatures?

B

	Low temperature	High temperature
A	not spontaneous	not spontaneous
B	spontaneous	not spontaneous
C	spontaneous	spontaneous
D	not spontaneous	spontaneous

67 The decomposition of limestone can be represented by the equation:

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

(a) Predict a sign for the enthalpy change of the reaction. $+\Delta H$

(b) Predict a sign for the entropy change of the reaction. $+\Delta S$

(c) Deduce how the stability of limestone changes with temperature.

high temp
$\Delta G = -T\Delta S$,
So is spontaneous

low temp
$\Delta G = \Delta H$, so not spontaneous

Exercises

68 The enthalpy and entropy changes for the reaction

$$A(s) + B(aq) \rightarrow C(aq) + D(g)$$

$+\Delta H$
$+\Delta S$

are $\Delta H^{\ominus} = 100\ kJ\ mol^{-1}$ and $\Delta S^{\ominus} = 100\ J\ K^{-1}\ mol^{-1}$

D

A The reaction is not spontaneous at any temperature.

B The reaction is spontaneous at all temperatures.

C The reaction is spontaneous at all temperatures below 1000 °C.

D The reaction is spontaneous at all temperatures above 1000 K.

Name:_____
Period:_____

69 Magnesium carbonate, $MgCO_3$, is a white solid that occurs in nature as the mineral magnesite. Magnesite decomposes to the oxide at temperatures above 540 °C.

$$MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$$

Identify the correct description of this reaction at 800 °C.

	ΔG	ΔH	ΔS
A	+	+	+
B	+	−	−
C	−	+	+
D	−	+	−

C

+ΔS (↑disorder)
+ΔH (breaking)
but ↑temp
ΔG = (+) − (very negative)
ΔG = −

70 Calculate $\Delta G_{reaction}$ for the thermal decomposition of calcium carbonate

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

from the following data, and comment on the significance of the value obtained.

Compound	$\Delta G_f^\ominus$ / kJ mol^{-1}
$CaCO_3(s)$	−1129
$CaO(s)$	−604
$CO_2(g)$	−394

$\Delta G = \Sigma G_{prod} - \Sigma G_{react}$

$= (-604 + -394) - (-1129)$

$= 131$ kJ mol^{-1}

very positive — so calcium carbonate is very stable & doesn't decompose spontaneously

Exercises

71 Calculate $\Delta G_{reaction}$ at 2000 K for the thermal decomposition of calcium carbonate from the data given in the worked example.

Compound	$\Delta H_f^\ominus$ / kJ mol^{-1}	$S^\ominus$ / J K^{-1} mol^{-1}
$CaCO_3(s)$	−1207	+92.9
$CaO(s)$	−635	+39.7
$CO_2(g)$	−394	+214

$CaCO_3 \rightarrow CaO + CO_2$

$\Delta S = (39.7 + 214) - (92.9) = 160.8$ J K^{-1} mol^{-1}

$\Delta H = (-635 + -394) - (-1207) = 178$ kJ mol^{-1}

$\Delta G = (178) - (2000 \times .1608)$

$= -144$ kJ mol^{-1}

Name:_____
Period:_____

72 Which property of an element has a value of zero in its standard state?

B (I) $\Delta H_f^\ominus$ (II) $S^\ominus$ (III) $\Delta G_f^\ominus$ → entropy is only ever 0 at absolute zero (which is theoretical)

A I and II **B** I and III **C** II and III **D** I, II, and III

73 The standard enthalpy change for the formation of ethanol, $C_2H_5OH(l)$, and its molar entropy are given in section 12 of the IB data booklet.

(a) Write an equation for the formation of ethanol.

(b) Calculate the entropy change for this process. The entropies of its constituent elements are:
$C(graphite) = 5.7\ J\ K^{-1}\ mol^{-1}$
$H_2(g) = 65.3\ J\ K^{-1}\ mol^{-1}$
$O_2(g) = 102.5\ J\ K^{-1}\ mol^{-1}$

(c) Calculate the standard free energy change of formation of ethanol at 500 K.

(d) Deduce whether the reaction is spontaneous at 500 K, and give a reason.

(e) Predict the effect, if any, of an increase in temperature on the spontaneity of this reaction.

a) $2C_{(graphite)} + \frac{1}{2}O_{2(g)} + 3H_{2(g)} \rightarrow C_2H_5OH_{(l)}$

b) $\Delta S = \Sigma products - \Sigma reactants$
$= (161) - ((2 \times 5.7) + (\frac{1}{2} \times 102.5) + (3 \times 63.5))$
$= -98\ J\ K^{-1} mol^{-1}$

c) $\Delta G = \Delta H - T\Delta S$
$= (-278) - (500 \times -0.098)$
$= -229\ kJ\ mol^{-1}$

found in data booklet

d) spontaneous, because $-\Delta G$

e) High temperature will $\Delta G = -T\Delta S$
so ΔG will be positive.

~~4. ΔH and $T\Delta S$ wrong~~

Name:_____
Period:_____

Exercises

74 What signs of $\Delta H^{\ominus}_{reaction}$ and $\Delta S^{\ominus}_{reaction}$ for a reaction result in a complete reaction at all temperatures?

C

	$\Delta H^{\ominus}_{reaction}$	$\Delta S^{\ominus}_{reaction}$
A	−	−
B	+	−
(C)	−	+
D	+	+

exothermic and disordered

75 Which conditions correspond to a system of equilibrium?

D

I The entropy of the system is at a maximum. ✓ $+\Delta S$

II The free energy of a system is at a minimum. ✓ $-\Delta G$

III $\Delta G^{\ominus}_{reaction} = 0$

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

76 Which values correspond to a reaction that can be reversed by changing the temperature.

B

	$\Delta H^{\ominus}_{reaction}$	$\Delta S^{\ominus}_{reaction}$	
I	−	−	✓
II	+	−	never
III	+	+	✓

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

77 Propene reacts with hydrogen in the presence of a nickel catalyst to form propane.

$$C_3H_6(g) + H_2(g) \rightarrow C_3H_8(g)$$

$-\Delta S$ $-\Delta H$

$\Delta H^{\ominus}_{reaction} = -123\ kJ\ mol^{-1}$; $\Delta S^{\ominus}_{reaction} = -128\ J\ K\ mol^{-1}$

Estimate the temperature range in which a mixture of all three gases will be present.

guess & check

78 The Haber process is an important process in which ammonia is formed from nitrogen and hydrogen:

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

$\Delta S^{\ominus}_{reaction} = -198\ J\ K^{-1}\ mol^{-1}$; $\Delta H^{\ominus}_{reaction} = -93\ J\ K^{-1}\ mol^{-1}$

Estimate the temperature range in which a mixture of all three gases will be present.