Enthalpy entropy and free energy worksheet answers





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Worksheet 2-3 - Calculations Involving the Equilibrium Constant

Foundations of Biology I - Fall 2013 Spontaneity Chart

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

**MG** = Gibbs Free Emergy All - Entholpy AS = Entropy T = Temperature

Fill out the missing blanks inside the chart. Effects of Temperature on the Spontaneity of Reactions

AH	48	۵G	Description
			Spontaneous at all T
	24		
			Spontaneous at low T; nonspontaneous at high T
		+/-	

## Remember of\_\_\_\_

i. ΔG < 0 reaction can spontaneously proceed to the right.</p>

 $A \rightarrow B$ 

 $z = \Delta G > 0$  reaction can spontaneously proceed to the left:

A 4 B

ר ע גר ע גר		
T = temperature in K 35 = change in entro	spy or randomness	
Complete the table for the sign of AG; +, - Of undetermined. When conditions allow for an undetermined sign of AG, temperature will decide spontaneity. Answer the questions below. 1. The conditions in which AG is always negative is when AH is(00)	AH AS AG - + + - + Undetermined - at and + + Undetermined - at and + + Undetermined - at and + + + Undetermined - at and + + + + + + + + + + + + + + + + + + +	
and AS is 2. The conditions in which AG is always positive AS is 3. When the situation is indeterminate, a low to enthalpy ) factor, and a high temperature to	e is when sH is and emperature toyons the ( entropy / toyons the ( entropy ) entholpy ) factor.	
<ol> <li>Answer Problems 4-6 with always, sometimes or n</li> <li>the reaction: Na(OH), → Na+(aq) + OH1 be spontaneous.</li> </ol>	(oq) + energy will <u>Alwa 75</u>	
<ol> <li>The reaction: energy + 2H<sub>2</sub>(g) + O<sub>2</sub>(g) → spontaneous.</li> </ol>	- 24,0 m Mever to	
<ol> <li>The reaction: energy + H<sub>2</sub>O00 → H<sub>2</sub>O00 w</li> <li>What is the value of sG if sH = -32.0 kJ, s5 ×</li> </ol>	+25.0 kJ/K and T = 293 K7 -7357 Kg	
<ol> <li>is the reaction in Problem 7 spontaneous?</li> <li>What is the value of AG if AH = +12.0 kJ, AS</li> </ol>		
10. Is the reaction in Problem 9 spontoneous?	119	



Define enthalpy entropy and free energy. How does entropy affect free energy. Is entropy free energy.

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Others are spontaneous because they lead to an increase in the disorder of the system (S > 0). Calculations of H and S can be used to probe the driving force behind a chemical reaction. What happens when one of the potential driving force behind a particular reaction. What happens when one of the system (S > 0). the system, which reflects the balance between these forces. The Gibbs free energy of a system at any moment in time is defined as the enthalpy of the system. G = H - TS The Gibbs free energy of the system is a state function because it is defined in terms of thermodynamic properties that are state functions. The change in the Gibbs free energy of the system that occurs during a reaction is therefore equal to the change in the entropy of the system. G = H - (TS) If the reaction is run at constant temperature, this equation can be written as follows, G = H - TS The change in the free energy of a system that occurs during a reaction can be measured under any set of conditions. If the data are collected under standard-state free energy of reaction (Go). Go = Ho - TSo The beauty of the equation defining the free energy of a system is its ability to determine the relative importance of the enthalpy and entropy terms as driving forces behind a particular reaction. The change in the free energy of the system that occurs during a reaction measures the balance between the two driving forces that determine whether a reaction is spontaneous. As we have seen, the enthalpy and entropy terms have different sign conventions. Favorable Ho < 0 Ho > 0 So > 0 So < 0 The entropy term is therefore subtracted from the enthalpy term when calculating Go for a reaction. Because of the way the free energy of the system is defined, Go is negative for any reaction that is favored by both the enthalpy and entropy terms. We can therefore conclude that any reaction taneous reactions:  $G_0 > 0$  Reactions are classified as either exothermic (H < 0) or for which Go is negative should be favorable, or spontaneous. Favorable, or spontaneous reactions: Go < 0 Conversely, Go is positive and So is negative. Any reaction for which Go is positive is therefore unfavorable, or non-spontaneous reactions: Go < 0 Conversely, Go is positive and So is negative. endothermic (H > 0) on the basis of whether they give off or absorb heat. Reactions can also be classified as exergonic (G < 0) or endergonic (G > 0) on the basis of whether they give off or absorb heat. Reactions can also be classified as exergonic (G > 0) or endergonic (G > 0) or the basis of whether the free energy of the system decreases or increases during the reaction. decide whether the reaction should proceed. The same can be said for reactions favored by neither enthalpy (Ho > 0) nor entropy (So < 0). Free energy of a Reaction The balance between the contributions from the enthalpy and entropy terms to the free energy of a reaction depends on the temperature increases. Go = Ho - TSo Since the entropy term will become more important as the temperature increases. Standard-State Free Energies of Reaction Go for a reaction can be calculated from tabulated standard-state free energy data. Since there is no absolute zero on the free energy scale, the easiest way to tabulate standard-state free energy data. free energy of the substance and the free energies of its elements in their thermodynamically most stable states at 1 atm, all measurements being made under standard-state conditions. Interpreting Standard-State Free Energy of Reaction? N2(g) + 3 H2(g) 2 NH3(g) Go = -32.96 kJ By definition, the value of Go for a reaction measures the difference between the free energies of the reactants and products when all three components of the reactants and products when all three components of the reactants and products when all components are present at 1 at many products when all components are present at 1 at many products when all components are present at 1 at many products when all components are present at 1 at many products when all components are present at 1 at many products when all components are present at 1 at many products when all components are present at 1 at many products when all components are present at 1 at many products when all components are present at 1 at many products when all components are present at 1 at many products when all components are present at 1 at many products when all components are present at 1 at many products when all components are present at 1 at many products when all components are present at 1 at many present at 1 at many present at 1 at ma the reaction has to shift to come to equilibrium. The fact that Go is negative for this reaction at 25oC means that a system under standard state is from equilibrium. The larger the value of Go, the further the reaction has to go to get to from the standard-state conditions, as shown in the figure below. N2(g) + 3 H2(g) 2 NH3(g) The value of G at that moment in time will be equal to the standard-state free energy for this reaction, Go. When Qp = 1: G = Go As the reaction at any moment in time is therefore said to be a measure of the energy available to do work. The Relationship Between Free Energy and Equilibrium Constants When a reaction leaves the standard state because of a change in the ratio of the products to the reactants, we have to describe the system in terms of non-standard-state free energies of reaction. The difference between Go and G for a reaction is important. There is only one value of Go for a reaction at a given temperature, but there are an infinite number of possible values of G. The figure below shows the relationship between G for the following reaction and the logarithm to the base e of the reaction and the logarithm to the base e of the reaction and the logarithm to the base e of the reaction and the logarithm to the base e of the reaction at a given temperature, but there are an infinite number of possible values of G. The figure below shows the relationship between G for the following reaction and the logarithm to the base e of the reaction at a given temperature, but there are an infinite number of possible values of G. The figure below shows the relationship between G for the reaction at a given temperature, but there are an infinite number of possible values of G. The figure below shows the relationship between G for the reaction at a given temperature, but there are an infinite number of possible values of G. 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The figure below shows the relation at a given temperature, but there are an infinite number of given temperature, but there are an infinite number of given temperature, but there are an infinite number of given temperature, but there are an infinite number of given tem side of this figure correspond to relatively small values of Qp. They therefore describe systems in which there is far more reactant than product. The sign of G for these systems is negative and the magnitude of G is large. figure describe systems in which there is more product than reactant. The sign of G is now positive and the magnitude of G is moderately large. The sign of G tells us that we don't have quite as far to go to reach equilibrium. The magnitude of G is moderately large. figure cross the horizontal and versus axes of this diagram are particularly important. The straight line crosses the vertical axis when the reaction quotient for the system is equal to 1. This point is equal to 1. This point is equal to 1. This point at each of the standard-state conditions, and the value of G at this point at each of the system is equal to 1. This point is equal to 1. This point at each of the system is equal to 1. The system is equal to 1. This point at each of the system is equal to 1. This point at each of the system is equal to 1. This point at each of the system is equal to 1. This point at each of the system is equal to 1. This point at each of the system is equal to 1. This point at each of the system is equal to 1. This point at each of the system is equal to 1. This point at each of the system is equal to 1. This point at each of the system of the system is equal to 1. This point at each of the system of which the straight line crosses the horizontal axis describes a system for which G is equal to zero. Because there is no driving force behind the reaction, the system must be at equilibrium. When Qp = Kp: G = 0 The relationship between the free energy of reaction at any moment in time (G) and the standard-state free energy of reaction (Go) is described by the following equation.  $G = Go + RT \ln Q$  In this equation, R is the ideal gas constant in units of J/mol-K, T is the temperature in kelvin, ln represents a logarithm to the base e, and Q is the reaction is zero (G = 0) when the reaction is zero (G = 0 is zero (G = 0). solve this equation for the relationship between Go and K. Go = - RT ln K This equation allows us to calculate the equilibrium constant for any reaction from the standard-state free energy of reaction, or vice versa. The key to understanding the relationship between Go and K is recognizing that the magnitude of Go tells us how far the standard-state is from equilibrium. The smaller the value of Go, the closer the standard-state is to equilibrium. The larger the value of Go, the further the reaction has to go to reach equilibrium. The relationship between Go and K for Common Reactions at 25oC Reaction Go (kJ) K 2 SO3(g) 2 SO2(g) + O2(g) 141.7 1.4 x 10-25 H2O(l) H+(aq) + OH-(aq) 79.9 1.0 x 10-14 AgCl(s) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-10 HOAc(aq) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 55.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 5.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 5.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 5.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 5.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 5.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 5.8 x 105 HCl(aq) + H2O H+(aq) + Cl-(aq) 5.6 1.8 x 10-5 N2(g) + 3 H2(g) 2 NH3(g) - 32.9 3.8 x 10-5 HCl(aq) + 2 H2(g) 2 NH3(g) - 32.9 x 10-5 HCl(aq) + 3 H2(g) 2 NH3(g) - 32.9 x 10-5 HCl(aq) + 3 H2(g) 2 NH3(g) - 3 H2(g) 2 NH The equilibrium constant for a reaction can be expressed in two ways: Kc and Kp. We can write equilibrium constant expressions in terms of the partial pressures of the gases (Kp). For reactions in solution, the equilibrium constants are not strictly constants are not strictly constants en out strictly constants are not strictly constants. standard-state is from equilibrium. Go = - RT ln K But the magnitude of Go depends on the temperature of the reaction. A good example of this phenomenon is the reaction in which NO2 dimerizes to form N2O4. 2 NO2(g) N2O4(g) This reaction is favored by enthalpy because it forms a new bond, which makes the system more stable. The reaction is not favored by entropy because it leads to a decrease in the disorder of the system. NO2 is a brown gas and N2O4 is colorless. We can therefore monitor the extent to which NO2 dimerizes to form N2O4 by examining the intensity of the brown color in a sealed tube of this gas. What should happen to the equilibrium between NO2 and N2O4 as the temperature is lowered? For the sake of argument, let's assume that there is no significant change in either Ho or So as the system is cooled. The contribution from the entropy term becomes smaller as the temperature is lowered. Go = Ho - TSo As the tube is cooled, and the entropy term becomes less important, the net effect is a shift in the equilibrium toward the right. The figure below shows what happens to the intensity of the brown color when a sealed tube containing NO2 gas is immersed in liquid nitrogen. There is a drastic decrease in the amount of NO2 in the tube as it is cooled to -1960C. The Relationship Between Free Energy and Cell Potentials The value of G for a reaction the reaction has to shift to reach equilibrium. The magnitude of G tells us how far the reaction is from equilibrium at that moment. The potential of an electrochemical cell is a measure of how far an oxidation-reduction reaction is from equilibrium. The Nernst equation describes the relationship between the free energy of reaction at any moment in time and the standard-state free energy of reaction. G = Go + RT In Q These equations are similar because the Nernst equations to the other by taking advantage of the following relationships between the free energy of a reaction and the cell potential of the reaction when it is run as an electrochemical cell. G = -nFE

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